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ACTIVITIES AND PROGRAM MODEL

Data Saves the Whales!

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Data Saves the Whales! was developed as part of the *Advanced Manufacturing and Prototyping Integrated to Unlock Potential* (AMP-IT-UP) project, funded by the National Science Foundation through its Math and Science Partnership program. A central outcome of the AMP-IT-UP project was the development of 1-week modules for core middle school math and science courses that were aligned with best practices as put forth in the Next Generation Science Standards and Standards of Mathematical Practice. Data Saves the Whales! is a middle school mathematics module that is set within a marine ecosystem. It focuses on independent and dependent variables and Cartesian coordinate graphing, and on math practices related to data representation—i.e. how data can be represented in different ways to communicate various messages to an audience. Students engage in a simulated investigation to collect oceanographic data, meant to mimic the experimental procedures used by marine scientists when collecting samples, and learn different methods of graphing the data to effectively communicate their findings. This module features work conducted by the research team of Dr. Ellery Ingall, Professor of Earth and Atmospheric Science at Georgia Tech, and integrates math skills with marine science and the concepts of food webs and the interdependence of organisms.

Keywords: Marine science education; Middle school mathematics; Data representation; STEM integration; Graphing; Coordinate systems

Introduction

In 2012, the National Science Foundation funded the *Advanced Manufacturing and Prototyping Integrated to Unlock Potential* (AMP-IT-UP) project through its Math and Science Partnership program to develop a comprehensive initiative to increase student interest and engagement in science, technology, engineering, and mathematics (STEM).[1] A central outcome of the project was a series of one-week modules for core middle school math and science instruction aligned with best practices put forth in the Next Generation Science Standards (NGSS 2013) and the Standards of Mathematical Practice (National Governors Association Center for Best Practices & Council of Chief State School Officers 2010). The modules promote STEM learning by engaging middle school students in project-based inquiry lessons that highlight scientific research and emphasize collecting, representing, visualizing, interpreting, and communicating authentic and compelling data. Though all modules require students to collect, graph, and analyze data, each module also specifically focuses on one of three general data practices—1) Experimental or Procedural Design; 2) Data Representation or Visualization; or 3) Data-Driven Decision Making. Five of the eighteen modules are contextualized within marine ecosystems, challenging students to collect and analyze data regarding the effects of oil spills and overfishing on the health of coral reefs and the hazards to whales posed by research ships in the Antarctic. The latter module, a middle school mathematics module entitled *Data Saves the Whales!*, is presented in detail below. All other modules are also available for free download at https://ampitup.gatech.edu (**Figure 1**).

The design of all modules was informed by research in the area of project-based inquiry learning (PBIL) (Harris et al. 2014; Krajcik et al.1998; Mehalik, Doppelt & Schuun 2008). PBIL curricula tend to focus on student-generated inquiry, employing a case-based reasoning model wherein students design and reflect on

[1] NSF project # 1238089.

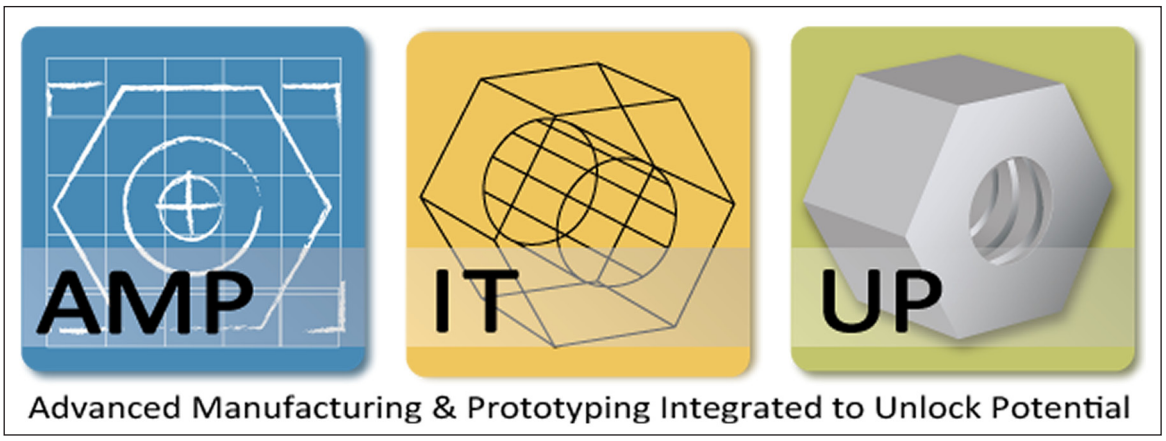

Figure 1: AMP-IT-UP Logo. All curriculum materials are available at https://ampitup.gatech.edu.

investigations to make decisions and develop understandings that enable them to solve a problem (Kolodner et al. 2003).

All modules also strive to promote, to the extent possible, the integration of the STEM content, incorporating science and engineering contexts and data collection investigations into activities that also require that students analyze data using both grade-level appropriate and foundational mathematics skills. In their report "*STEM Integration in K-12 Education*", the National Research Council outlined a number of goals of an integrated K-12 STEM education, ranging from increasing interest and engagement in STEM, to enabling students to make connections and transfer knowledge among STEM disciplines, to improving 21st century competencies (NRC 2014). These types of student outcomes are all goals of the AMP-IT-UP project.

For five years AMP-IT-UP curriculum developers, researchers, and educators designed the curriculum materials, piloted them in four middle schools, made iterative changes based on formative data, and conducted extensive empirical research regarding their impact on students and teachers. The mathematics and science modules were designed to provide teachers with highly scaffolded instructional materials that would be educative and promote changes in teacher practice in the classroom. The modules demonstrate how project-based learning and the implementation of integrative practices related to data practices can effectively enable students to master core math and science disciplinary concepts and practices while promoting high levels of student engagement.

Overview

Data Saves the Whales! is a week-long mathematics module set within a marine ecosystem that focuses on independent and dependent variables and Cartesian coordinate graphing and on data practices related to data representation—i.e. how data can be represented in different ways to communicate various messages to an audience. During this investigation students analyze plankton and temperature data collected at different ocean depths in the Antarctic to determine whether a research vessel will collide with whales. They construct coordinate graphs of the data to identify whether the data are linear or non-linear, discern whether a variable is independent or dependent in the relationship, and reason quantitatively about the data relationships. The module was designed for middle school math classes but also connects to what students may be learning in their earth or life science classes about marine ecosystems and the Antarctic. In general, it takes approximately five 50-minute class periods to complete this activity. Like the other AMP-IT-UP modules, it follows the BSCS 5E instructional model that is based on the constructivist theory of learning and allows for students to construct their own knowledge based on experiences (Bybee et al. 2006).

The *Data Saves the Whales!* module highlights marine research in biogeochemistry, oceanography, and climate science. It specifically features Dr. Ellery Ingall, Professor of Earth and Atmospheric Science at Georgia Tech, and his graduate students. Other AMP-IT-UP modules highlight the multi-institutional *Ecosystem Impacts of Oil and Gas Inputs to the Gulf* (ECOGIG) project and the coral reef work of Dr. Mark Hay, Professor of Biology at Georgia Tech.

Background Information for Teachers

The instructional materials, which are all available for free download at https://resources.ceismc.gatech.edu/amp/whale, were created and revised based on years of classroom implementation through the

AMP-IT-UP project. The student materials include a student edition text that guides students through the experience and the accompanying student worksheets that students use to showcase what they are learning. The downloadable materials also include teacher educative materials that were designed to help teachers implement the modules successfully. The teacher edition is the student text annotated with tips and suggestions to help guide teachers through the module. The annotations include sample answers that students might give to questions, reminders to prepare materials ahead of time, and additional content to explore. The teacher preparatory guide is intended to help teachers plan their lessons. It contains information that might be required in lesson plans, such as relevant standards, essential questions, and key terms. It also provides a synopsis of each section of the module and visually maps the module content onto the 5E-learning model. The main activity in *Data Saves the Whales!* uses canisters that need to be prepared ahead of time. Supplemental module documents include a materials list and an instructional guide for preparing the canisters.

Preparation

Students engage in a simulated investigation during this module, meant to mimic the experimental procedures used by marine scientists when collecting samples. Each group of three to four students is given six canisters labeled with the depths where the samples were collected. Each canister contains a two-inch by two-inch resealable bag filled with a pre-determined mass of dried "plankton" (here modeled with split peas) and a paper thermometer indicating the temperature at the depth where the sample was collected. Since each group of students receives only six canisters from different depths, they must share their data with the whole class to reveal the complete data profile. The specific mass of split peas to be placed in each canister and instructions about how to label each canister are explained in the material preparation instruction guide. Each student group should have access to a digital scale. Teachers need to prepare the containers ahead of time, but they should be able to be used by multiple sequential classrooms (**Figure 2**).

Engage

The Engage phase of this module is designed to capture student interest and connect them with a real-world problem. It introduces students to the Antarctic marine environment, Dr. Ingall's research and graduate students, and the overarching challenge that awaits students. Student interest is captured as they are

Figure 2: The materials students use for their simulated investigation including canisters, digital scales, student texts and accompanying student pages. Courtesy of Steven Taylor.

introduced to the icebreaker research ship *ODEN* and are virtually transported to the Antarctic to learn more about the environment and the animals and organisms, specifically plankton, that live there. Plankton play an important role in the aquatic ecosystem, feeding on algae and helping to manage the algae population. They are also a valuable food source for whales as well as fish, birds, and various other aquatic mammals. A high plankton population is often used as an indicator of a healthy ecosystem. This math module connects what students have learned about food webs and the interdependence of living things in their science classes to the skills they are learning in their math class.

There are three videos in this section that introduce students to the Antarctic and situate them with the challenge. In the first video, "*ODEN*," students observe the Antarctic environment as it was filmed from the ship, including the unforgiving landscape and marine animals. During the second video, "*Julia's Research*," Julia Diaz, a Ph.D. student in the Ingall Lab at the time, discusses her research interests around phytoplankton and how phosphorus cycles in the ocean. She also demonstrates how samples are collected. The third video, *"CTD—Conductivity, Temperature, and Depth"*, demonstrates the robotic instrument (the CTD) that scientists aboard the *ODEN* use for collecting samples in the ocean. The instrument has many canisters that are open at the ocean's surface and close when the CTD reaches a certain depth. The containers collect water samples, including organisms such as plankton, at each depth. Students are asked to consider what factors might affect how deep plankton can live beneath the surface, setting the stage for their upcoming investigation. After the CTD is brought back on board, scientists evaporate the water and study the remains, one of which is dried plankton.

At this point students learn their challenge for this module. Whales that swim near the ocean surface are sometimes struck by passing ships, which can injure the whale and harm the boat. Dr. Ingall predicts that if they can determine the depth at which whales feed on plankton, that can help ensure that ships like the *ODEN* can avoid hitting the whales. So, students are tasked with helping Dr. Ingall determine the depth where whales will most likely feed on plankton in the waters around Antarctica as well as the temperature of the water that the plankton prefer.

Explore

In the Explore phase of this module, students actively investigate the problem of how to determine 1) the depth where whales are most likely to feed and 2) the water temperature where plankton live. Since students won't be taking a field trip aboard the *ODEN*, they will conduct a simulated experiment in their classrooms, imitating the experiments done aboard research ships. The simulation was designed using data collected by actual researchers in the Antarctic, lending authenticity to this activity. For the simulation, groups of students are given small canisters, similar in appearance to the containers used by the CTD robot, that are pre-labeled with the depth where the samples were collected. When students open a canister, they learn the temperature of the water where that sample was collected and they find a bag containing dried "plankton," here modeled using split peas, which they weigh on a digital scale (**Figure 3**). These canisters all contain unique amounts of materials representing real data, and it is important that teachers prepare them ahead of time and that students are careful to not lose or mix up items. There is a recipe sheet included with the material resources that contains instructions on how to prepare the canisters.

Data Saves the Whales! is a module that stresses the skills and concepts associated with data representation. In this module students collect and analyze data and find different ways of representing that data. In the first part of the activity they learn about pictographs and how to represent data of varying magnitudes using different numbers of a particular symbol or using symbols of different sizes (e.g. larger symbols represent larger numbers). They then create two pictographs using the canister data from the whole class—one graph to represent the water temperature of the samples at each depth and one to represent plankton weight. To do this, each individual group of students analyzes data from six canisters representing different depths and records their data on their *Temperature Data Sheet* and *Plankton Weight Data Sheet* student pages. For their recorded temperature and plankton weight, students calculate how many symbols are needed to accurately represent their data and then plot those symbols on their pictograph student pages. Since each group received data for only six depths, it is necessary for groups to share their data with the entire class so that students have a complete set of data. With these data, students create pictographs on their *Temperature Pictograph Sheet* and *Plankton Weight Pictograph Sheet* student pages showing how plankton weight and temperature vary with depth. The pictographs aid students in visualizing how temperature and plankton vary with depth, which helps them to answer the initial challenge.

Figure 3: Student group weighing the dried plankton from a canister (modeled by split peas) during the Explore phase. Courtesy of Steven Taylor.

Explain

The Explain phase of this module is where students connect their experiences with the mathematics and technical concepts they are learning. This is the phase where learners connect what they have done so far with the required mathematical standards, including: independent and dependent variables, ordered pairs, Cartesian coordinate graphing, and linear and non-linear relationships. The student text includes content explaining why this is a module focused on the practice of data representation; students had previously created pictographs to show different ways of visualizing and representing data and now they learn how mathematicians similarly use Cartesian coordinate graphs to also represent data. The text explains what Cartesian coordinate graphs are and how they are created and includes key vocabulary: independent and dependent variables, coordinates of a point, and ordered pair.

Previously students collected and recorded the temperature and plankton weight for the depths 80 to 230 feet beneath the surface. Now they use these data as the basis to learn how to create ordered pairs of numbers representing depth vs. temperature and depth vs. plankton weight. Working independently, students use the data already recorded on their *Whale Challenge Data Tables* student sheet and create the ordered pairs for depth vs. temperature values and depth vs. plankton weight, following the examples provided. They learn that the data they collected represents the independent and dependent variables that will become their X and Y coordinates.

Elaborate

In the Elaborate phase students extend their understanding of the mathematical content they have been learning thus far (data representation, ordered pairs, and independent and dependent relationships) to a new experience. Specifically, students use the ordered pairs that they created of depth vs. plankton weight and depth vs. water temperature and plot those on their own Cartesian coordinate graph.

The ordered pairs that students recorded on the *Whale Challenge Ordered Pairs* student page (**Figure 4**) include the X and Y coordinates that they then plot on their graphs. Students plot both sets of ordered pairs

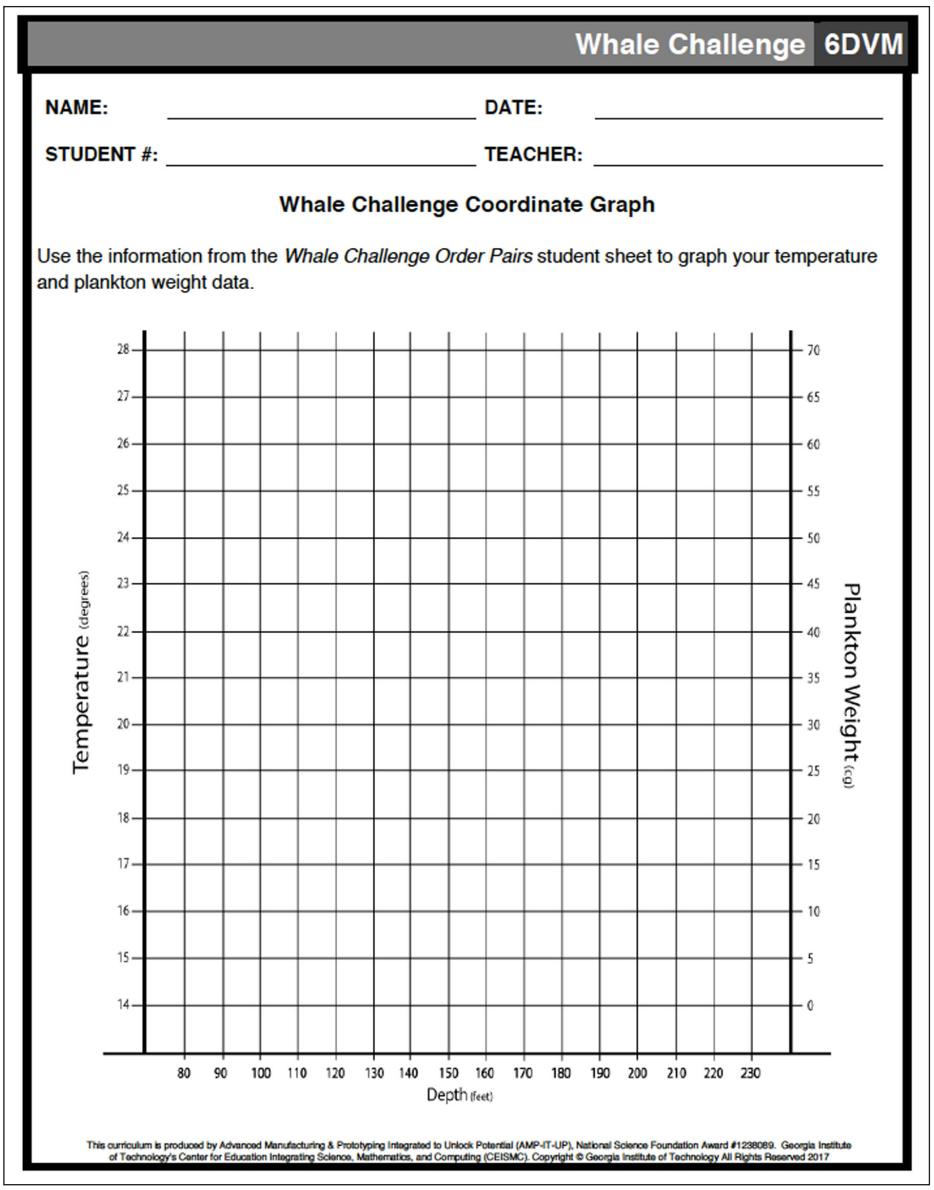

Figure 4: Whale Challenge Coordinate Graph student page where students plot the ordered pairs for their investigation (temperature vs. depth and plankton weight vs. depth), to aid with visualizing trends in data.

on the same graph, something that they may not have much experience doing. STEM professionals often plot two dependent variables on the same graph to better visualize if there is a relationship between the variables. Students will follow this lead to graph their plankton data on the same graph as the temperature data to explore whether there is a relationship between those variables and how they vary with ocean depth. Plotting two sets of data on the same graph may be an intimidating task for students. Teachers may need to lead students through plotting the first couple of points as a whole-class activity. Students are instructed to use two different symbols to represent the temperature and plankton weight data, either circles and Xs or two different colors, etc. This helps students easily visualize the two sets of data and to identify relationships.

Once all of the ordered pairs are plotted, students are instructed to connect those points revealing trends in the data. This connects with what students learn about linear and non-linear relationships.

Evaluate

This module offers multiple opportunities to evaluate student learning through both formative and summative assessments. The student pages are essentially practice, guiding students in this experience as they transition through the phases of collecting and analyzing data from their simulation and creating ordered pairs and graphing that data in order to explore relationships. For teachers looking for final grades from this module, there are two student pages in particular that are recommended for summative assessments:

Interpreting Graphs and *Letter to Dr. Ingall.* As students answer the questions on the *Interpreting Graphs* page, they analyze the graphs on the *Whale Challenge Coordinate Graph* sheet to identify the independent and dependent variables for both plots and to determine whether the relationships are linear or non- linear. Students were initially challenged to determine the depth where plankton feed and the temperature of the water where most plankton live. With the class data from their investigation graphed, students are able to visualize the results and answer those questions. Students also use mathematical expressions to make predictions about the dry weight of plankton and the ocean temperature at a depth of 125 feet. After using the mathematical expression for a line to make a prediction, they analyze their graphs to see if their predictions were validated. The final task for students is to return to the challenge and communicate their findings to Dr. Ingall. The student page *Letter to Dr. Ingall* gives students a scaffolded letter to help them communicate whether ships will hit whales as they feed on plankton and the water temperature that plankton prefer.

Before writing their letters, they are given one additional piece of information about the *ODEN*. The bottom of the ship is 39 feet below the surface of the water. When students analyze their graphs and determine where the whales are likely to be feeding, they can communicate with certainty that the boat will not reach the whales while they feed.

Conclusion

This STEM-integrated module, which can be used to address several Common Core Mathematics standards, connects students with real-world scenarios, uses authentic data, and is contextualized within a marine ecosystem that relates to content from earth and life science. Although it was written for sixth grade math classes, the content and student pages can be adapted for students of varying abilities or additional grades. In this module, students use manipulatives to explore the relationship between the concentration of plankton, the temperature of the ocean, and the depth below the ocean surface and use this information to predict the behavior of feeding whales. The module went through several iterative cycles of curriculum development, professional development, classroom implementation and revision before being made available for wider dissemination.

Teachers played an important role in this process as they shared significant feedback about their implementation of modules through surveys, observations, and interviews with the AMP-IT-UP team. Two of the teacher materials created for each module, the annotated teacher guide and the teacher preparatory guide, contain many of the suggestions that teachers have shared for successful implementation as well as pitfalls to avoid, such as, "preview the module and have materials ready in a manner to distribute easily," and "tell the students to only have one container open at a time so they don't get any data mixed up."

Teachers also found great value in having students use digital versions of student pages, especially for recording data. In *Data Saves the Whales!,* individual groups are given a few samples for their investigation. The opportunity to record their data on a shared digital document allows them to see other groups' data as it is recorded, giving insight to a more complete data set. As one teacher noted,

> "I used a Google sheet to post the class-wide data for the graphs, which made the process much easier. This was a great way to let students share their results in an organized, efficient manner. Additionally, it led to great discussion when someone had data that was an outlier. (Most were able to identify their own mistakes in calculations)."

Another teacher highlighted great discussion about data with their students. When calculating the weight of plankton, many of their students made the error of not subtracting the weight of the bag. The student-reported data, "was perfect dialogue for reinforcing skewed data points. I was able to simply facilitate and [students] discussed the results as we completed the class graph together. They pointed out the errors to each other without me having to intervene."

During the interviews, teachers also mentioned that the modules successfully supported the teaching of data practices because of the relatability of the content to the real world and to the lived experiences of students and because the content is integrated across classes and content areas. Teachers reported that students transferred knowledge to new contexts, "even including social studies and language arts. They talk about, 'okay, let's come up with a procedure,'" and they even attributed gains on state mathematics assessments to the AMP-IT-UP curriculum.

The AMP-IT-UP curriculum materials would be beneficial to any science, math, or STEM educator that is looking for novel ways of teaching data practices contextualized through STEM integrated content.

Resources

- Link to the AMP-IT-UP website for all curriculum offerings: https://ampitup.gatech.edu.
- Link to the *Data Saves the Whales!* files: https://resources.ceismc.gatech.edu/amp/whale.

Mathematics and Science Standards

Relevant Common Core Math Standards for 6th Grade

Expressions and Equations:

- *Apply and extend previous understandings of arithmetic to algebraic expressions (6.EE.A.2.c)*
- *Reason about and solve one-variable equations and inequalities (6.EE.B.6)*
- *Represent and analyze quantitative relationships between dependent and independent variables (6.EE.C.9)*

The Number System:

- *Understand a rational number as a point on the number line. Extend number line diagrams and coordinate axes familiar from previous grades to represent points on the line and in the plane with negative number coordinates (6.NS.C.6.b, 6.NS.C.6.c)*

Supported Next Generation Science Standards

Disciplinary Core Ideas:

- *ESS2.C: The Roles of Water in Earth's Surface Processes*
- *LS2.A: Interdependent Relationships in Ecosystems*

Science and Engineering Practices:

- *Analyzing and Interpreting Data*
- *Constructing Explanations and Designing Solutions*

Crosscutting Concepts:

- *Patterns*

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

Jayma Koval led the manuscript writing, with contributions from other authors. She also designed the teacher educative materials for *Data Saves the Whales!* Marion Usselman and Jeff Rosen developed the curriculum with assistance from other members of the AMP-IT-UP team, and Meltem Alemdar directed the data collection and analysis. All authors have read and approved the manuscript.

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