Data-driven Inquiry
in the PBL Classroom

Linking maps, graphs, and tables in biology

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Data-driven inquiry as a science practice and instructional approach can provide a powerful context for project-based learning (PBL). Students engage in data-driven inquiry when they explore a rich data set and observe patterns, ask questions suggested by the data, and pursue answers about underlying phenomena. Krajcik (2015) describes five features of PBL:

- Seeking solutions relevant to learners' lives;

- Planning and performing investigations to answer questions;

- Collaborating with other students, teachers, and members of society;

- Producing artifacts;

- Using technology tools when appropriate.

Data and the *Next Generation Science Standards*

Students' ability to work with and interpret data is a significant focus of the *Next Generation Science Standards* (NGSS Lead States 2013). A recent review of the performance expectations (PEs) for grades K–12 found that when one includes PEs related to Practice 4 (analyzing and interpreting data) and those for which data use is implied (e.g., Practice 7: engaging in argument from evidence), 46% of PEs involve data skills that are distributed across all grade bands (46% in elementary, 49% in middle school, and 43% in high school) (Kastens 2015). Data-driven inquiry is interdisciplinary by nature, and the ability to work with, make meaning from, evaluate, and communicate with data is also emphasized in the *Common Core English Language Arts and Mathematics Standards* (NGAC and CCSSO 2010).

Data, particularly accurate, professionally collected data, provide a rich context for open-ended, complex student-driven investigations that are fundamental to PBL approaches. However, these types of data are often difficult to find, manipulate, visualize, and analyze by non-professionals, and a key challenge is making them accessible for teaching and learning (Krumhansl et al. 2012).

In science classrooms, students often use graphs to learn about change of a variable over time or the relationship between two variables. Less frequently, science students employ maps to study geographic distributions of things such as climate change or the spread of invasive species. Still less often, students engage in scientific inquiry with maps and graphs as multiple representations of the same phenomenon. This article describes and illustrates the potential for these familiar but powerful visualizations to enable data exploration that supports PBL when they are embedded in a free, web-based environment designed for learning about ocean life (Figure 1).

Ocean Tracks (see "On the web") is an online program created by an interdisciplinary team of marine biologists, curriculum developers, web designers, teachers, and education researchers, aimed at engaging students in work with big data in an accessible format. It offers subject matter—marine predators including sharks, seals, and tuna—that many students find interesting (perhaps due in part to the popularity of TV shows such as *Wicked Tuna* or *Blue Planet*). Students follow these animals' journeys through the Pacific Ocean using scientific data and are equipped with tools to visualize and analyze predators' movements as well as the physical and chemical attributes of their environment.

The data from tracking marine animals provide windows into various intriguing phenomena such as migration patterns, the effects of ocean topography and currents on food supplies, the occurrence of biological hotspots where many marine animals congregate, and the life cycle of the tracked species. The

FIGURE 1

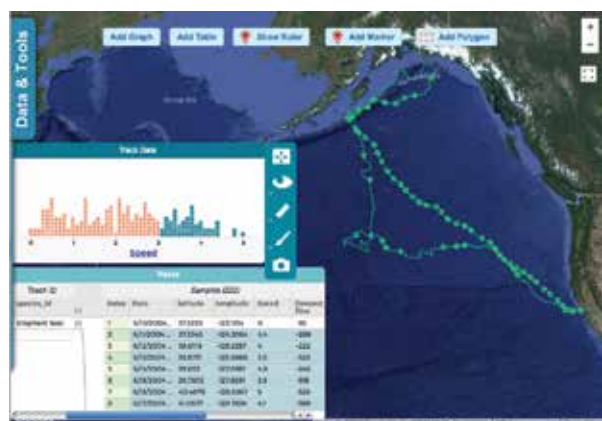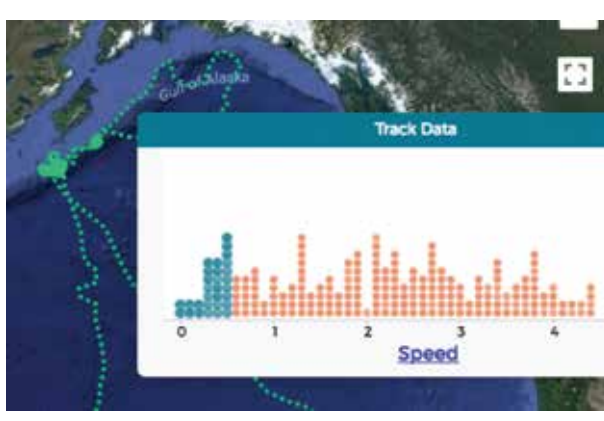### The distribution of speeds of Elephant Seal 302.

FIGURE 2

The lowest speeds of Elephant Seal 302.

program's suite of authentic data, flexible GIS and graphing tools, and extensive content supports seems tailor-made for PBL, especially if an introductory session provides the foundation for students' independent investigations. Tools from the Common Online Data Analysis Platform (CODAP—see "On the Web") have been embedded in Ocean Tracks, expanding its capabilities. This expanded "OT+CODAP" interface (see "On the Web") offers the additional ability to visualize simultaneously data in tables, graphs, and maps, through the integration of CODAP tools into the Ocean Tracks interface, greatly expanding students' options for exploring the data.

Meet Elephant Seal 302

An initial demonstration can serve to introduce students to an online data interface, orient them to the data and analysis tools, and pique their curiosity about the data. For example, in OT+CODAP, you might project the track of Elephant Seal 302 along with a data table and graph showing the distribution of its speeds (Figure 1). Select the highest speeds in the distribution by clicking and dragging over the data points. As you do so, different areas of the track light up in the map.

Initial questions to prompt students' thinking might include, "What do you observe about the seal's movement? What ques-

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OT + CODAP INTERFACE

OT+CODAP

The OT+CODAP environment is a "mashup" of two NSF-funded projects, Ocean Tracks and the Common Online Data Analysis Platform (CODAP).

About Ocean Tracks: The Ocean Tracks interface and curricula are designed to engage students in the critical scientific practices of developing questions, planning and carrying out investigations, and analyzing and interpreting data. It features professionally collected animal tracking, environmental, and human impact data that have been made accessible for student and teacher use through specially designed visualization and analysis tools. *http://oceantracks.org*

About CODAP: CODAP is free, browser-based, open-source software designed for grades 6–14 as a data exploration environment and platform on which developers of educational materials can build. *http://codap.concord.org*

About OT+CODAP: The combined interface features the Ocean Tracks map and all of the tracking, environmental, and human impact data, with the addition of two buttons: *Add Table* and *Add Graph*. These additions allow users to load floating CODAP data tables and graphs onto the map view, with all of their affordances. Most importantly, all of the visualizations are interoperable—meaning that a selection or change in one visualization (e.g., the selection of a set of points in a table or on a graph) is instantly manifested in the other visualizations, allowing users to relate patterns observed in one visualization (e.g., in a graph) to another (e.g., on the map). *http://oceantracks.org/otcodap-map-prototype*

Getting Started

Follow these steps to set up the *Elephant Seal 302* demo:

1. In your browser (Chrome is recommended) go to *http://oceantracks.org/sites/all/OT-CODAP-map/.*

2. Click the *Add Table* button. Then click the *Add Graph* button. You may need to adjust the size and position of the

table and graph so they don't cover the track. You can also drag the map.

3. Remove "Deepest Dive" from the graph's vertical axis.

4. Change the attribute displayed on the horizontal axis to "Speed."

5. Select a range of speeds by clicking and dragging in the graph.

Exploring the White Shark Café

Students can use graphs to compare distributions from within and outside of the area of the Pacific known as the White Shark Café. Follow these steps to set up the distributions:

1. In the Data & Tools pullout, select at least six white shark tracks to display on the map (e.g., #501900, #502000, #600100, #600200, #600800, #602500), and remove Elephant Seal #302 if still displayed.

2. Click the *Add Table* button. Then click the *Add Graph* button twice, and adjust the size and positions so they don't cover the map.

3. Click the *Add Polygon* button and select an area of the map where a lot of the sharks seem to be traveling. Click on the map to start drawing and to add additional markers around the area of interest. Complete your selection by clicking on the first marker.

4. In each graph, remove "Day of Year" from the horizontal axis.

5. In one graph, use the "eye" menu to hide the *unselected* points to create a distribution of data within the White Shark Café. In the second graph, hide the *selected* points to create a distribution of data outside of the White Shark Café. (Note: Students can label these graphs by clicking on and replacing the titles. Refer to Figure 6, p. 32.)

6. Compare distributions for different variables by changing the attribute on the vertical axes.

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tions do you have? What might the seal be doing in the high-lighted areas of the ocean?" Students may suggest that the seal is going fast so it can get to its feeding grounds. To investigate, you might select the lowest speeds (Figure 2) and ask, "What do you notice about the highlighted points in the map, and what do you think is going on?" Students' suggestions that the seal must be spending a lot of time in one place and their conjectures about why (e.g., breeding or feeding) are signs of inquiry.

Students then try to make sense of three representations—map, graph, and table—and the relationships among them. Linked data selection—in which selecting data in any one of the representations causes the same data to be selected in the others—helps highlight these relationships and reveal patterns that would not be immediately apparent in a single representation. The low-speed points in the graph show up mostly in a small cluster on the map, and, looking in the table, it's evident that they are close together in time as well.

Maps include a lot of information in addition to latitude and longitude. In fact, the relative position of things on a map—from cities to seals—rather than their coordinates is often most interesting. In the example in Figure 1, the cluster of low-speed elephant seal track points seems to be right on the edge of the Aleutian Trench. Could that be relevant? What other data would you need to determine whether this area was a feeding ground?

As a class, you might revisit OT+CODAP and overlay the map with chlorophyll concentration as measured from Earth-orbiting satellites (Figure 3). Assuming that chlorophyll is an indicator of food abundance, its relatively high levels near this cluster of points may lend support to the feeding grounds hypothesis.

Student investigation: White Shark Café

After the brief demonstration and discussion, it's time to turn your students loose for small-group investigation on the myste-rious great white shark. OT+CODAP (see "On the web") pro-vides access to a library of information about each of the species for which it has tracks (Figure 4). Begin with a short reading assignment on sharks' feeding habits, breeding behaviors, adap-tation, conservation, and tagging technologies to set the context for student investigations.

Prompt students to think about the number of tracks they will need to review to identify patterns in the sharks' move-ments. Those shown in Figure 5 (p. 32) show the high concen-tration of sharks in the area dubbed the "White Shark Café." (As of this writing, scientists are still trying to determine why the sharks go there and what they are doing.)

One question worth investigating might be, "What makes the Café special?" With a little work and the aid of the "Add Polygon" tool, students can create graphs that compare distri-butions of measurements (such as sharks' deepest daily dives) taken *within* the Café with measurements taken *without* (Fig-ure 6, p. 32). Those are clearly different depth distributions. What student questions do they spark?

Maps, graphs, and tables facilitate inquiry

The OT+CODAP map includes data about the tracks of ma-rine animals, shorelines of continents and islands, ocean floor topography, and overlays for temperature and chlorophyll de-rived from satellite images. These data invite questions and conjectures from students:

- "How fast do tuna travel on their way from California to Japan?"

- "There are a lot of different elephant seals in this one small area. I bet they're there at the same time and doing something together."
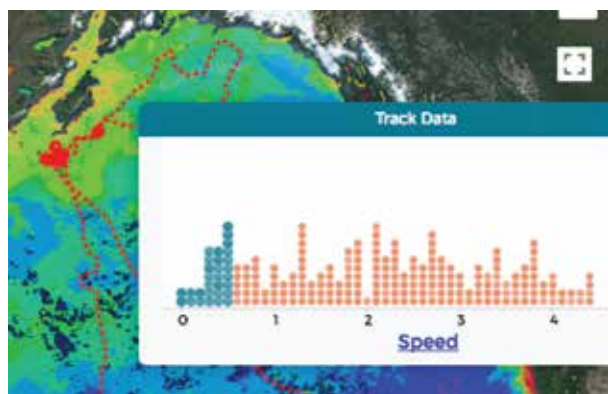

Map overlaid with chlorophyll concentration.

The species tracked by the Ocean Tracks site.

- "What draws sharks to the White Shark Café? Are they feeding or mating? Or is there some other reason they go there?"

Graphs of the data give students tools to answer their questions and investigate their hypotheses. For example, plotting the mean speeds for the portions of the tracks where three tuna are moving most directly across the ocean (Figure 7) reveals that the tuna average 3–5 km/hour for that portion of their journey. In contrast, we find speeds between 1.1 and 1.6 km/hour for the portions of the track on either end of the journey.

So now we know how fast they travel and that their speeds vary according to where they are in their migration. But perhaps this prompts us to wonder whether they eat during their transpacific journey, a question these data will not help us answer.

Students can easily forget that a track is not a continuous entity; it is comprised of measurements taken by the electronic
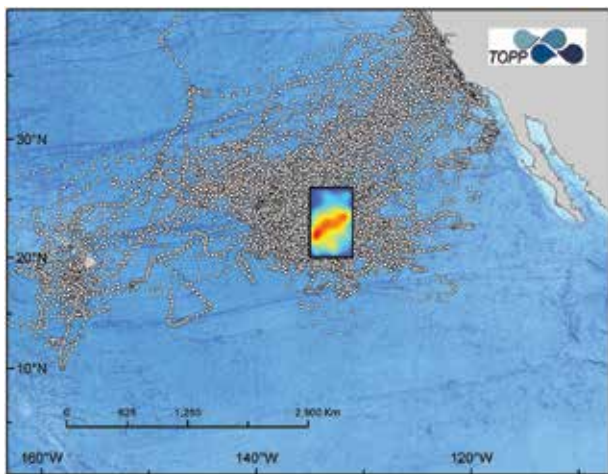
tag attached to the animal's body. Graphs—with their plotted point representations of the measurements—can help students keep the nature of the data firmly in mind. The discrete nature of the track data can become a focus of inquiry. For example, the depth data for elephant seals is dramatically bimodal, but selecting one of the clumps in the graph shows that these points are spread out geographically over the tracks (Figure 8). Students can (as the authors have) puzzle over what is going on and look for answers in the data and other sources.

Finally, tables can provide students with a better sense of the data's structure and, particularly when dynamically linked, help them decipher more abstract map and graph representations. This can be especially important when working with complex, hierarchical professional data sets. For example, not only does the OT+CODAP table reinforce the frequency of measurements taken along each track (i.e., daily), it allows students to

FIGURE 6

Measurements taken within the café vs. outside the café.
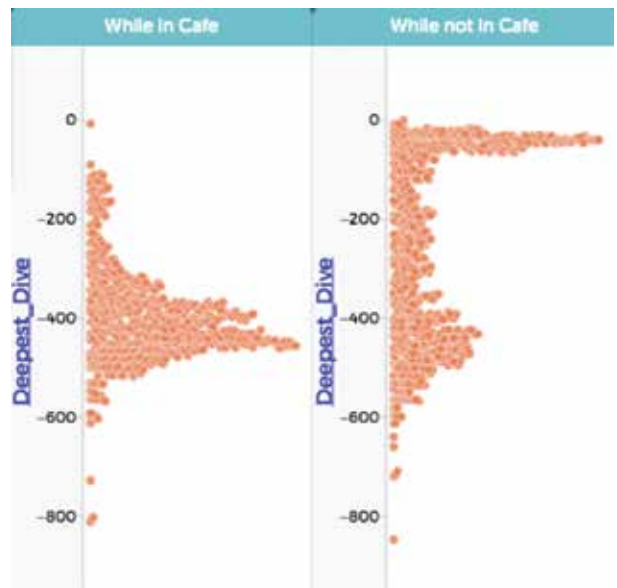
quickly scan the range of variables associated with each location and time (e.g., sea surface temperature, chlorophyll concentration, speed, and depth) and consider the potential usefulness of each in their investigations. Selecting points in the graph or map quickly illuminates the corresponding species, animal, and track points in the table, which can help students maintain their orientation and scaffold their interpretation.

Experiences with students

The Ocean Tracks interface and accompanying curriculum materials have been tested in high school classrooms to examine their potential to support student-driven, independent investigations using complex, professionally collected data. We also looked at the role that novice-friendly maps and graphs played in helping students identify spatial and temporal patterns in tracking and environmental data, collecting qualitative and quantitative data to support their claims about animals' behavior, and generating new questions that could be answered through further analysis. Students were interested in and engaged by the authentic data available in Ocean Tracks and were successful in using the interface to take measurements, describe patterns, and generate hypotheses based on the data.

We shared the expanded OT+CODAP interface (featuring additional representations, graphing capabilities, and analysis tools) with high school seniors to gather their input on how
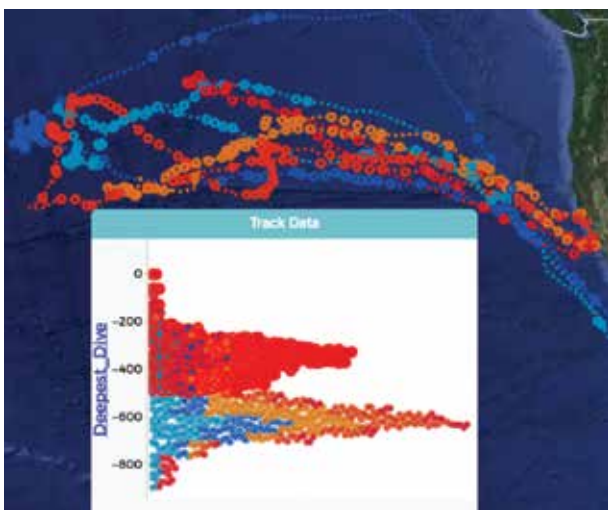
FIGURE 7

The mean speeds of the three tuna.
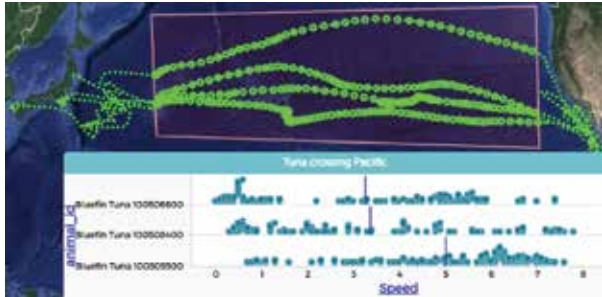
more-extensive graphing tools and linkages between graph, map, and table visualizations could help users make sense of the tracking data. We wondered if they would discover patterns that are hidden or obscured by viewing the data in any single representation. Finally, would they be drawn into further inquiry? Within a few minutes of orienting students to the new interface, they were able to accurately decipher the graphs displaying data from multiple species and tracks, identify patterns in the data, and generate ideas about the animals' behaviors based on those patterns. With support, students were

FIGURE 8

Depth data for elephant seals.

also able to create and interact with novel maps and graphs of their own, choosing to further investigate their ideas.

Conclusion

The *NGSS* practices of analyzing and interpreting data and engaging in argument from evidence call for students to make extensive use of data skills. In a PBL classroom, this translates to using appropriate technology to plan and perform investigations around relevant and complex phenomena, using data and data representations as the basis for collaborative exploration, discovery, and communication. We created an environment for students to investigate their own questions about marine biology using real scientific data as well as linked maps, graphs, and table representations. This open-ended set of easy-to-use and engaging visualization tools provides virtually limitless possibilities for processing, visualizing, and analyzing data, and opens the door to entirely new lines of inquiry, allowing students to go wherever their curiosity takes them. ■

ON THE WEB

CODAP: *http://codap.concord.org*
Ocean Tracks: *http://oceantracks.org*
OT+CODAP: *http://oceantracks.org/otcodap-map-prototype*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

HS-LS2. Ecosystems: Interactions, Energy, and Dynamics

Performance Expectations

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Analyzing and Interpreting Data Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.	Students use graph and map tools to estimate and visualize statistical measures such as the mean and to examine patterns and relationships related to animals' behavior.
Using Mathematics and Computational Thinking Use mathematical representations of phenomena or design solutions to support and revise explanations.	After identifying biological hotspots in the Pacific Ocean, students examine human impacts data on the map and propose solutions to mitigate negative effects on hotspot ecosystems.
Constructing Explanations and Designing Solutions Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	Students read about the tagging technologies used to collect the data featured in Ocean Tracks and consider the limitations of these data based on how they were generated.
Engaging in Argument From Evidence Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.	Students generate claims about why marine predators might be spending more time in certain areas of the Pacific Ocean, based on the data available.
Disciplinary Core Idea	
LS2.A: Interdependent Relationships in Ecosystems Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease.	Students use data to make claims about the environmental conditions that support feeding and breeding behaviors for marine predators. They can identify areas of the ocean that feature these conditions and assess the threat of negative impacts from human activity.
Crosscutting Concepts	
Scale, Proportion, and Quantity Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.	Students identify patterns and make claims about the behaviors of an individual animal in its ocean environment, relate those to patterns observed about multiple animals of the same species, and relate those to patterns observed about an entire ecosystem.
Stability and Change Much of science deals with constructing explanations of how things change and how they remain stable.	Students use data to examine how animals' behaviors and migrations change or remain stable over time and over changes to environmental conditions.