PAPER

Inspiring Future Marine and Data Scientists Through the Lure of *Ocean Tracks*

AUTHORS

Randall E. Kochevar
Education Development Center, Inc., Waltham, Massachusetts, and Hopkins Marine Station, Stanford University

Ruth Krumhansl
Kira Krumhansl
Education Development Center, Inc., Waltham, Massachusetts

Cheryl L. Peach
Scripps Institution of Oceanography, University of California, San Diego

Erin Bardar
Josephine Louie
Education Development Center, Inc., Waltham, Massachusetts

Jessica Sickler
Lifelong Learning Group, Columbus, Ohio

Julianne Mueller-Northcott
Amy Busey
Silvia LaVita
Jacqueline DeLisi
Education Development Center, Inc., Waltham, Massachusetts

ABSTRACT

The Oceans of Data Institute (ODI) at the Education Development Center (EDC), Inc.; Stanford University; and the Scripps Institution of Oceanography have been collaborating, with the support of three National Science Foundation grants over the past 5 years, to bring large scientific data sets into secondary and postsecondary classrooms. These efforts have culminated in the development of a Web-based student interface to marine science data called *Ocean Tracks* (http://oceantracks.org), which incorporates design principles based on a broad range of research findings in fields such as cognitive science, visual design, mathematics education, and learning science. The *Ocean Tracks* interface was tested in high school classrooms in spring and fall of 2013 with a total of 195 high school students. These tests indicate that students appeared to find many aspects of the interface simple and intuitive to use. Teachers and students indicated that working with real data was highly engaging, pointing to the tremendous potential for "big data" to transform the way science is taught. Interest among college faculty in *Ocean Tracks* indicates a need in undergraduate classrooms for similar tools that allow students to interact with data. So in the fall of 2014, we began to collect baseline data on students attending undergraduate oceanography classes at the Scripps Institution of Oceanography (Scripps) and Palomar College, where we will also be developing curricula and conducting classroom tests. Preliminary results from this work are presented here.

Keywords: Ocean Tracks, data literacy, big data, marine science, data science

Introduction

The fact that it was real animals being tracked was cool.... I learned a lot about elephant seals and biodiversity hotspots. It was interesting that so many animals go to the California coast.
—Undergraduate student reflecting on the *Ocean Tracks* Web interface

"Big data" has become a big deal. The adjective "big" has an evolving meaning but refers not just to the ever increasing *volume* of data available to use in scientific research but also to the dizzying *velocity* at which real-time data are generated, and the expanding *variety* of data that are generated as new sensors and technologies are deployed to quantify the nuances of the natural, built, and social environments (Dijcks, 2013). The use of data as a decision driver has expanded into every scientific, industry, and business enterprise (Manyika et al., 2011). Not only is big data pushing the boundaries of scientific discovery, but car mechanics, nurses, real estate agents, and teachers are now all expected to use data in their professions. Analyzing data, discerning meaningful patterns, and extracting useful information have become gateway skills to full participation in the workforce and civic engagement in the 21st century, and individuals skilled in the variety of tasks and duties required to acquire, aggregate, clean, organize, and analyze these data sets are in high demand.

There's been widespread recognition of the large and growing gap between the need for a workforce skilled in working with big data and the supply of qualified graduates (Manyika et al., 2011; Shaw, 2014). Where do students acquire these skills? Most students enrolled in traditional science laboratories often work with small data sets that they collected themselves. Although work with small data sets teaches important foundational skills, students are not adequately engaged in developing a new and broader set of skills necessary to extract meaning from large, complex data sets. The nature of the new data analytical skills that students need was clarified by an occupational profile of the "big-data-enabled specialist," which was recently generated and validated by more than 150 experts from a broad variety of industry sectors (Oceans of Data Institute [ODI], 2014a). Among the array of skills highlighted, the profile emphasizes the need for graduates who are able to define problems and articulate questions that can be addressed by large, complex data sets. It also revealed a need for scientists and technologists who are able to develop appropriate analytical methods and tools that reflect a deep knowledge of a variety of data sources (beyond what they have collected themselves). The study strongly endorsed the critical need for "soft skills" such as analytical thinking, critical thinking, and problem solving and asserted that a successful big data-enabled specialist should be a seeker of patterns, open-minded, and curious (ODI, 2014b).

Although the definition of big data is not well established in the public sphere, those concerned with educating K-16 students define big data as data sets that are *Complex* (i.e., they include multiple parameters or data types), *Large* (i.e., they include more data than are appropriate to answer any particular question), *Interactively accessed* (i.e., the user has choices, typically online, about what data to examine and how to visualize and analyze those data), and *Professionally collected* (i.e., they go beyond what students or ordinary citizens are able to collect themselves). To work effectively with these so-called CLIP data sets, students must have the ability to go beyond routine analyses. For example, students who are skilled in CLIP data set analyses must have the ability to select appropriate professionally collected data to investigate a question, create a variety of unique data visualizations appropriate to answer a question, relate multiple data parameters to each other, and use multiple lines of evidence to support a hypothesis.

The increasing availability of scientific CLIP data sets poses a tremendous opportunity to develop these skills. More broadly, carefully constructed use of authentic scientific data in the classroom enables students to engage in learning activities that are more deeply inquiry based. It offers the potential for higher development of problem-solving skills, addresses more complex concepts, and offers greater relevance to students' lives than traditional learning activities (Hotaling, 2005; Parsons, 2006; Simmons et al., 2008). Learning research has garnered considerable evidence that knowledge acquired by students via the simple "taking in" or memorization of information is fragile and can be superficial. To build a more robust and enduring understanding of content, students in science classrooms need to actively think with new information, connecting and applying concepts as they construct scientific explanations for observed phenomena (National Research Council [NRC], 2000, 2012a). The NRC framework, which forms the basis for the recently released *Next Generation Science Standards* (NGSS), asserts that participation in the practices of science "makes students' knowledge more meaningful and embeds it more deeply into their world view" (NGSS Lead States, 2013). At the undergraduate level, research suggests that inquiry-based activities are underutilized in undergraduate classrooms and that faculty still largely rely on a lecture format in their courses. In recognition of this, the President's Council of Advisors on Science, Technology, Engineering, and Mathematics (PCAST) "advocate and provide support for replacing standard laboratory courses with discovery-based research" at the undergraduate level (PCAST, 2012). The incorporation of student investigations with an array of large scientific data sets, now available online, provides a significant opportunity to do so.

However, scientific data portals and analytical tools are generally designed for experts, which poses a significant barrier to their use in the classroom. Recognizing this, the National Science Foundation (NSF) funded the *Oceans of Data* project to gather knowledge relevant to the design of student-friendly interfaces to scientific data from a broad range of fields such as cognitive science, visual design, mathematics education, and learning science. The resulting guidelines, published in *Visualizing Oceans of Data: Educational Interface Design* (Krumhansl et al., 2014), were then applied to the design and development of a student interface to marine science data called *Ocean Tracks*. This article describes what we are learning from classroom testing of *Ocean Tracks* at the high school and (now) undergraduate levels, focused on developing

The Tagging of Pacific Predators (TOPP) program began in 2000 as part of the International Census of Marine Life. Using electronic tags, a multidisciplinary team of 75 scientists from five nations deployed more than 4,300 tags on 23 different species of apex predators in the North Pacific Ocean, including whales, seals, sharks, tunas, seabirds, sea turtles, and even squid. By the year 2010, more than 365,000 days of tracking data had been collected, representing the largest data set of its kind. The electronic tags used in the TOPP program included tiny archival tags that record information on light (used to calculate position), temperature, and depth; pop-up satellite archival tags that record similar data but release automatically from the animals at a preset time and telemeter their data via satellite back to the laboratory; and satellite tags that allow transmission of position and oceanographic data in realtime. By the end of the TOPP program, these technologies had reached a sufficient level of reliability and precision such that they are now routinely feeding oceanographic data into NOAA's Integrated Ocean Observation System (IOOS), which is used to predict ocean weather around the world.

students' skills in working with CLIP data.

The *Ocean Tracks* Interface

Funded by the NSF in 2012, *Ocean Tracks: Investigating Marine Migrations in a Changing Ocean*—a collaboration between the Education Development Center (EDC), Stanford University, and technology partner EarthNC—provides customized access to data collected by the Tagging of Pacific Predators program, along with physical oceanographic data sets from the National Oceanic and Atmospheric Administration (NOAA) and NASA (http://oceantracks.org). The ability to visualize the movements of free-ranging marine species has only come about in the past decade due to recent developments in electronic tagging technology (see sidebar). These tags have revealed fascinating patterns in habitat usage by these large marine animals and have raised critical questions about their future persistence in ocean ecosystems (Block et al., 2011; Hazen et al., 2012; Maxwell et al., 2013). The *Ocean Tracks* map interface and accompanying analysis tools enable students to be at the frontier of this field of knowledge and to engage in classroom learning activities that address the same kinds of questions being considered by wildlife researchers, such as, "How do you design conservation strategies for highly mobile species whose habitat usage is projected to change as the climate changes in the future?"

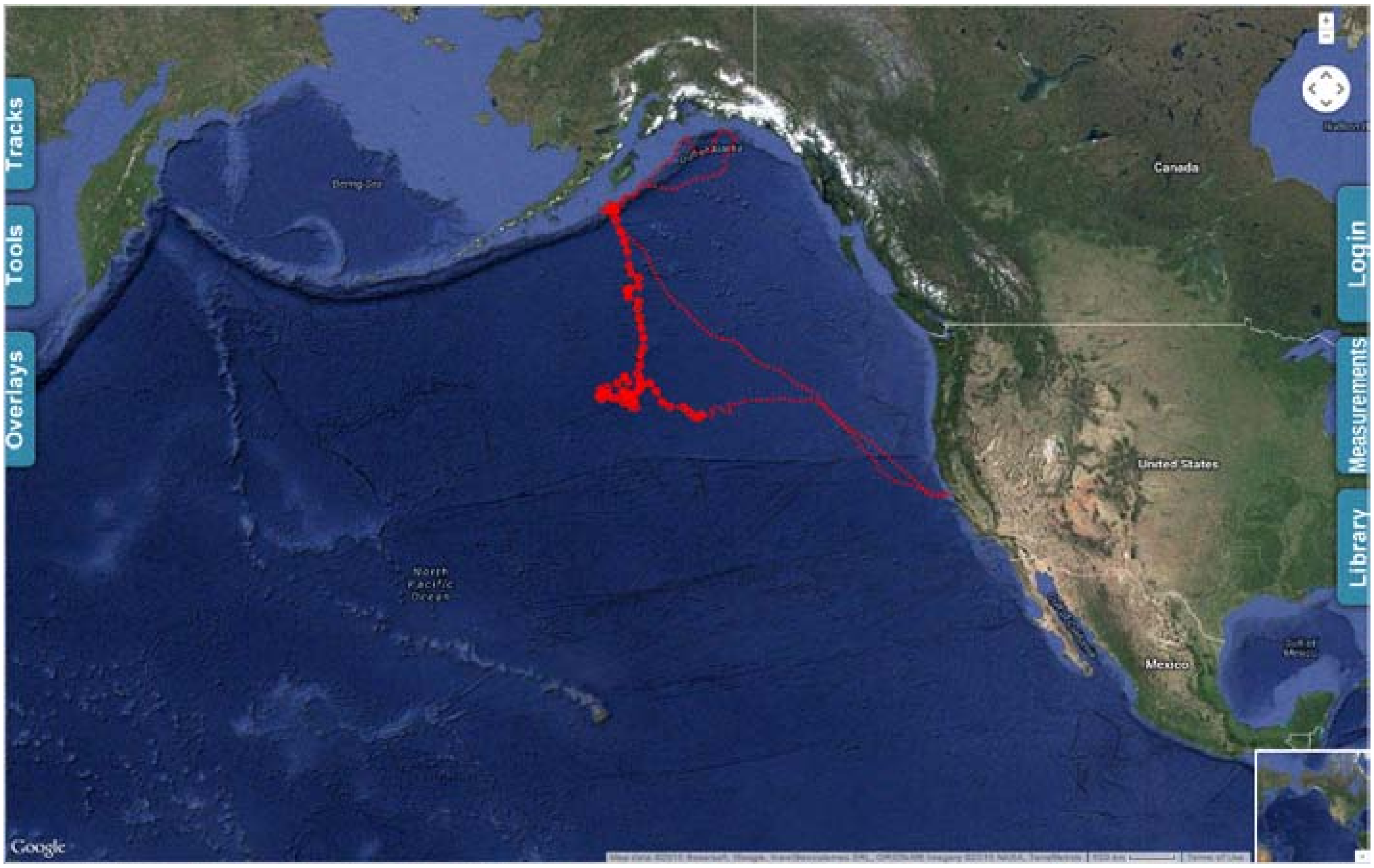
The core of the *Ocean Tracks* interface is a familiar, Google Maps–based view of the earth, centered on the North Pacific Ocean (Figure 1). When the interface is launched, a red line (the track of a northern elephant seal) appears on the map, marking the seal's path northwest from the California coast to Alaska's Aleutian Islands, where it loops around before swimming south and returning to the beaches of California. The map is surrounded on both sides by pull-out tabs labeled Tracks, Tools, Overlays, Login, Measurements, and Library. Using these tabs, users are able to add or remove tracks from the map, dynamically graph data associated with a specific track (e.g., daily maximum diving depth and daily average speed), or add more data layers (e.g., sea surface temperature and chlorophyll *a*). Users can log in to annotate and save map views as well as record data in a data entry table structured specifically for the data types in the interface. The Library contains custom multimedia content about the animals, tools, and technologies and provides access to video tutorials that guide users through the use of each interface function.

Beyond providing access to data that have typically been out of reach but may be of great interest to students, the *Ocean Tracks* interface was designed to optimize students' opportunities to focus their cognitive resources on viewing and comparing data to test hypotheses, while minimizing the time spent on downloading, filtering, and creating displays (Krumhansl et al., 2014). By automating many of the complex and time-consuming processes necessary to make customized data representations, students are able to delve deeper into making meaning and building more sophisticated understandings of the data.

Using the *Ocean Tracks* interactive map and data analysis tools, students are able to explore and quantify patterns in the migratory tracks of sharks,

FIGURE 1

Ocean Tracks utilizes the Google Maps interface, which we found most students to have already used extensively—alleviating the need for instructors to teach users routine functions like scrolling and zooming in and out. It also features tabbed pull-out menus that give users access to more sophisticated tools, which interact with the map display.



elephant seals, and other marine animals in the northern Pacific Ocean by taking measurements, such as speed and diving depth, to support hypotheses about marine animal behavior (Figure 2). The interface then supports students in relating these behaviors to fluctuations and trends in physical oceanographic variables, such as sea surface temperature and ocean currents (Figure 3).

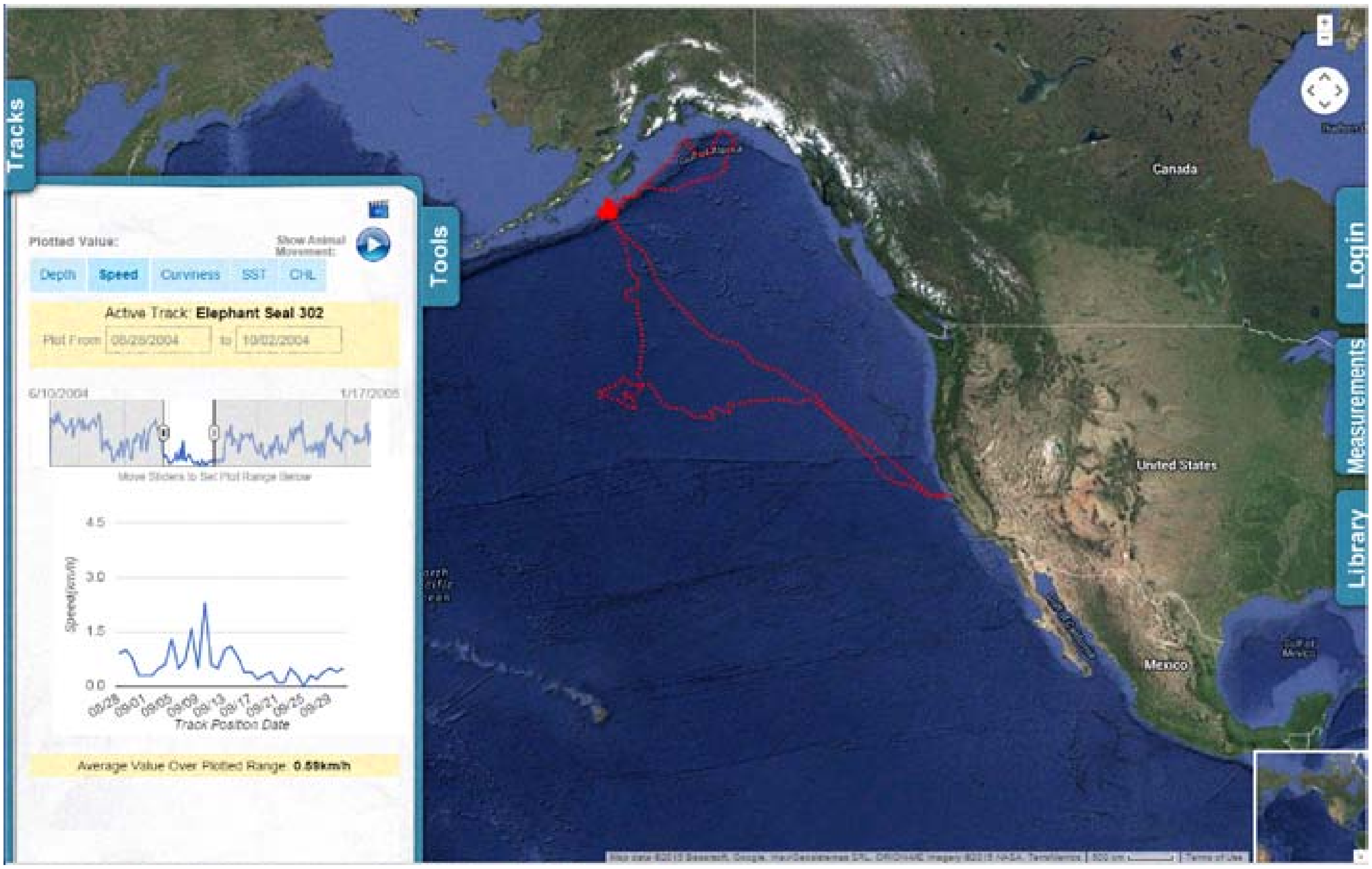
These interface features allow students to engage with the data in investigations that mirror those currently being conducted by scientists to understand the broad-scale effects of changes in climate and other human activities on top predators in ocean ecosystems (Block et al., 2011; Hazen et al., 2012; Maxwell et al., 2013). By involving students with these authentic data sets, *Ocean Tracks* supports the teaching of content related to marine ecology, including productivity, ocean circulation and physics, and global climate change.

High School Classroom Testing

Iterative development of alpha and beta versions of the interactive Web interface was informed by two rounds of classroom pilot testing of *Ocean Tracks* with high school students and teachers in spring and fall of 2013 (Table 1). Drawing on multiple data sources (Table 2), we examined the usability of the interface in classroom settings and the range of data skills that students were able to demonstrate when investigating *Ocean Tracks* data. The classroom tests also provided opportunities to gather information about the types of supports needed (such as curriculum, teacher guides, and video tutorials, all available at http://oceantracks.org) to develop students' abilities to use CLIP data sets to learn about the natural world. In addition, our research examined how teachers implemented draft *Ocean Tracks* curriculum modules, the challenges and successes they

FIGURE 2

The *Ocean Tracks* interface allows users to take measurements of animal tracks using a customized set of tools. A "time slider" is used to select specific track points, shown in bold red, and visualize a plot of depth, speed, and curviness of the track over the selected interval.



perceived during implementation, and the ways in which *Ocean Tracks* can be used to meet curricular goals and teaching standards.

The interface and supporting materials were revised in between the first and second pilot tests in accordance with needs that arose from analyses of Pilot 1 data. During both pilot tests, we collected data in the form of student surveys, student focus group interviews, student screencast recordings, student work, classroom observations, and teacher logs. Because most of the collected data were qualitative, the project team developed coding schemes for each data source and summarized findings across these sources related to interface usability, types of data skills displayed, and areas of student engagement. Primary findings from Pilot 2 data are discussed below.

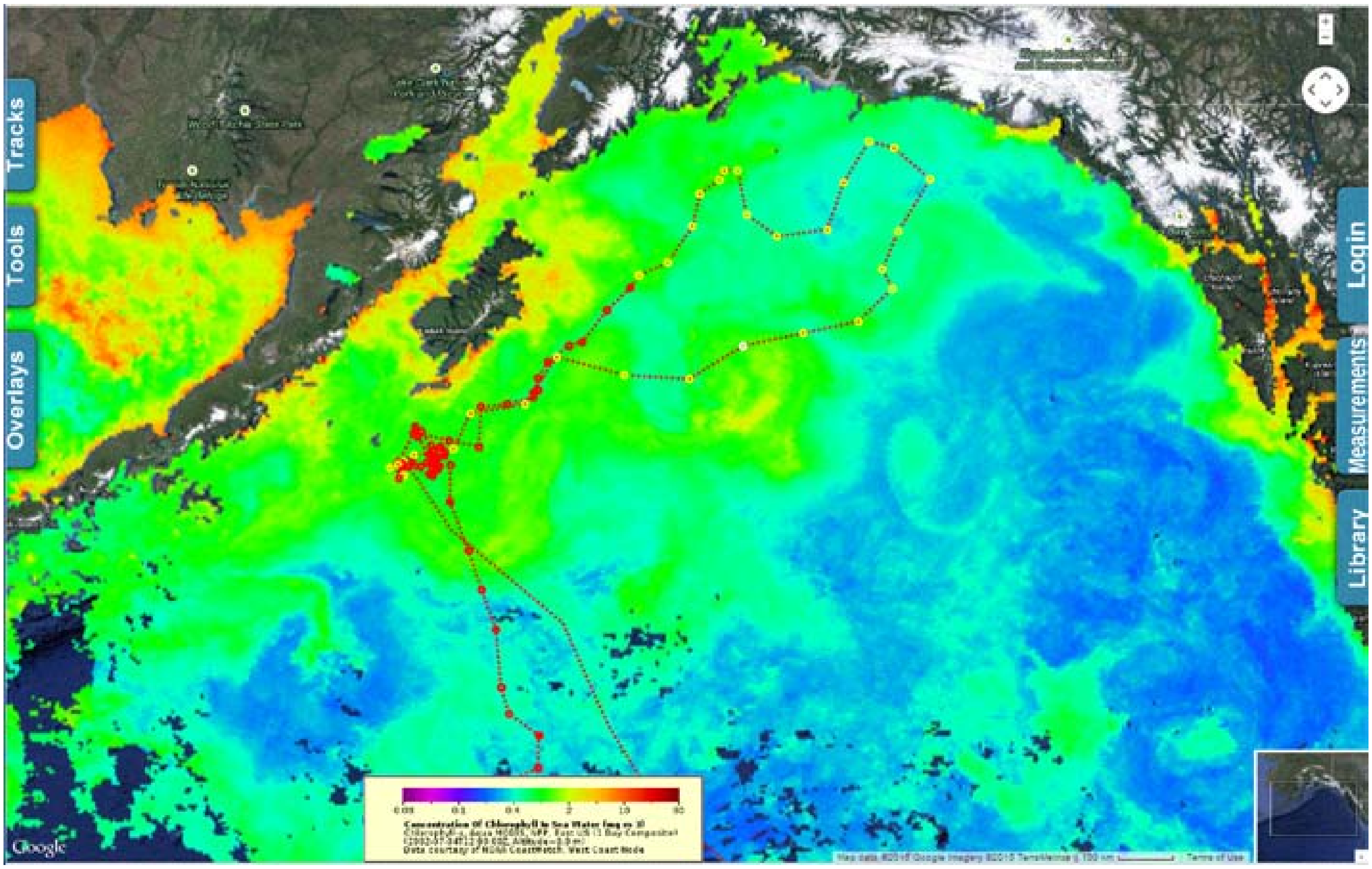
Findings

Data from 22 screencast recordings collected and analyzed from the second pilot test indicate that students appeared to find many aspects of the interface simple and intuitive to use. Students were observed performing with ease each of the following major interface functions: turning on animal tracks and finding data for specific track points, activating tracks and tailoring intervals along time-series graphs for specific track or oceanographic variables, selecting map overlays corresponding with individual animal tracks and track segments, selecting multiple animal tracks and using the hotspot tool to reveal species hotspots, annotating maps with map markers, navigating to and within the *Ocean Tracks* library to find relevant information, and zooming and panning around the primary map view. Data from classroom observations were consistent with these findings: Observers noted that most students found it easy to navigate the major functions of the interface and to access the animal tracking and oceanographic data available.

We also found that *Ocean Tracks* provided students with opportunities

FIGURE 3

The *Ocean Tracks* interface also allows users to display data overlays showing sea surface chlorophyll (shown) and temperature. Track points are colored yellow along the regions of the track that correspond to the date range of the overlay to aid users in linking monthly conditions represented by the data overlay to track points occurring during the same period.



to demonstrate important data skills. In an analysis of 23 student work assignments that were randomly sampled from the 92 that were collected, the vast majority of assignments (87%) contained a data visualization such as a map, table, or graph that students had generated to address a question posed in the *Ocean Tracks* draft curriculum (Figure 4). In at least 70% of sampled work assignments, students described relationships between two or more data variables and presented an interpretation of a data pattern using background information drawn from the *Ocean Tracks* library or another source. In over 60% of sampled work assignments, students produced a

TABLE 1

Ocean Tracks classroom tests: dates and sample characteristics.

	Date	Duration	Teachers (*n*)[a]	Students (*n*)	Course Titles	Grade Levels[b]	Settings[c]
Pilot 1	Spring 2013	5–6 weeks	3	61	Marine biology, biology, urban ecology	9–12	Suburban/town, urban
Pilot 2	Fall 2013	4–6 weeks	4	134	Same as above	Same as above	Same as above

[a]The three teachers who participated in Pilot 1 also participated in Pilot 2. An additional marine biology teacher from one of the Pilot 1 schools joined in Pilot 2. During both pilots, one marine biology teacher participated with two classrooms of students.
[b]The biology class targeted students in Grade 10. The marine biology classes contained students in Grades 11–12, and the urban ecology class included students in Grades 9–12.
[c]The biology and marine biology classes were conducted in schools in suburban/town settings. The urban ecology class was in a school in an urban setting.

TABLE 2

Data collected during *Ocean Tracks* pilot tests.

	Pilot 1	Pilot 2
Student surveys[a]	32 collected (68% response rate)	117 collected (87% response rate)
Student focus group interviews[a]	3 (8–13 students each)	4 (9–17 students each)
Student screencast recordings[b]	15	22
Student work assignments[c]	–	92 collected 23 analyzed
Classroom observations[d]	30	19
Teacher logs[e]	29	28

[a]Student surveys were collected, and focus group interviews were conducted at the end of each pilot test.

[b]Student screencast recordings were collected primarily during the initial weeks of each pilot test. Each recording captured the screen activities and vocalizations of individual or paired students as they navigated the *Ocean Tracks* interface and conducted a data investigation during a class period. During Pilot 2, one or more recordings were collected for seven individual students and two paired students over a period of 4 weeks.

[c]During Pilot 2, 92 samples of student work were collected, and 23 were randomly selected for analysis. We sampled approximately 25% of all work assignments submitted by three teachers; for a fourth teacher, we sampled three of eight (or 38%) of submitted assignments.

[d]Classroom observations were conducted by multiple project team members and produced written field notes following a common observation protocol. Each separate set of field notes was counted as an observation.

[e]Teachers were asked to reflect on the pilot activities by completing an initial log, weekly interim logs during *Ocean Tracks* implementation, and a final, summative log.

claim based on data measures or visualizations and presented reasoning for how data measures supported that claim. The following quote is a high school student's response to a question posed in the *Ocean Tracks* draft curriculum about where the prey of elephant seals may be located, illustrating the types of quantitative and evidence-based reasoning that the program can encourage and support.

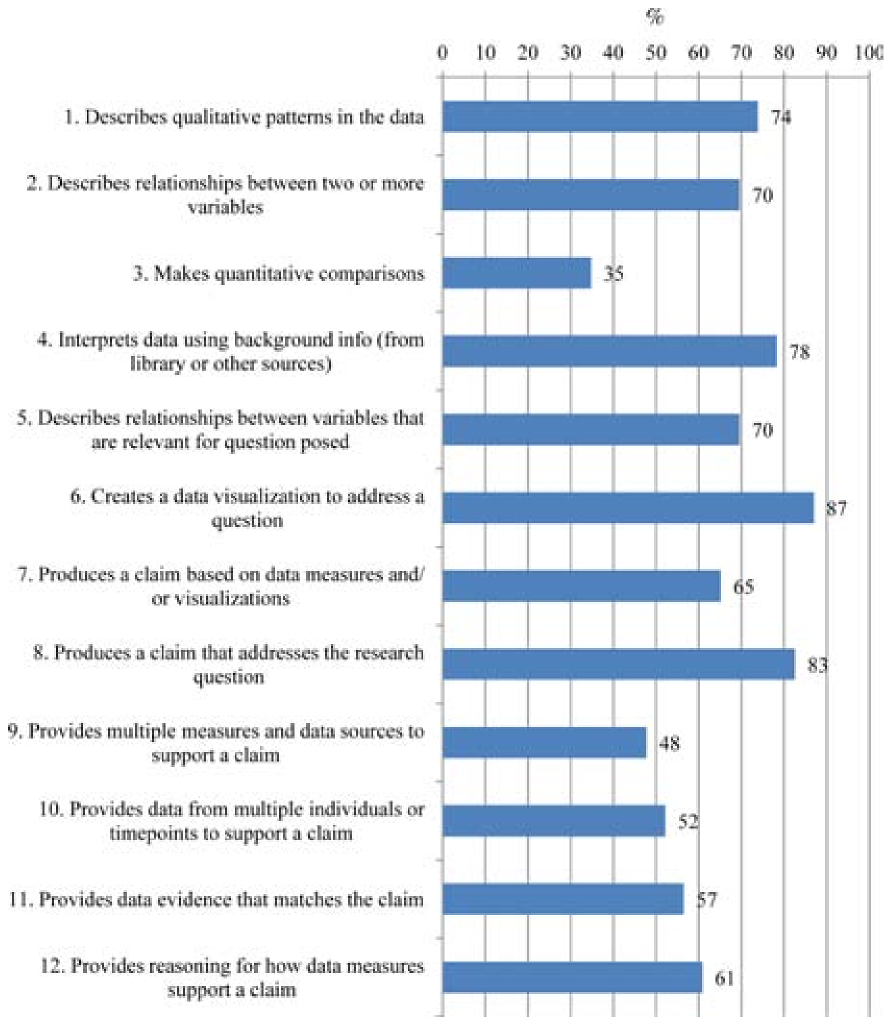
> *There is a major difference in seal behavior between the months of July and August. In July, it appears that the seal was passing through a rather nonproductive part of the ocean, due to a curviness factor of 1.35, and an average speed of 2.4 km/h and an average depth of −525.6 m. The fact that the curviness factor is so low and the speed so high shows that the seals were traveling straight through that part of the ocean, like a tourist on a highway traveling between monuments and attractions.... In August, however, the seals' curviness factor rose drastically to 2.7 while speed dropped to 1.23 km/hr...the average depth was also greater than the average depth in July indicating that the seal was diving more often to greater depths, most likely as a result of the presence of more food. Based on this data, it is evident that the location of the seal's prey is predominantly located in the region of seal tracks during the month of August. Data from the chlorophyll distribution map further supports this claim because chlorophyll concentration was 2 mg/m*^{3} *during the month of August, whereas during July this concentration was around 0.3 mg/m*^{3}*, showing that the section of the ocean in the August location was much more productive.*

In another exercise, students were asked to identify biological hotspots in the Pacific Ocean and to examine the data to generate ideas about the oceanographic processes that created these hotspots. (Hotspots are areas on a map that have a particularly high track-point density.) To identify biological hotspots, students use a customized tool in the *Ocean Tracks* interface that identifies areas of the highest track-point density for the tracks displayed on the map. Students then use map overlays to identify linkages between habitat usage and oceanographic parameters (Figure 5).

We found evidence that *Ocean Tracks* is an inherently interesting learning environment by nature of the data to which students are given access. Of the 117 responses received to the open-ended survey question, "What did you like most about Ocean Tracks?," 87 students (74%) said that the animals and their migration tracks were the most interesting aspects of the *Ocean Tracks* interface. Teachers identified that students were engaged by the fact that they were analyzing "real" data.

FIGURE 4

Percentage of student work assignments with evidence of specific data skills, *Ocean Tracks* Pilot 2 (total $N = 23$).



> *And it was real. That made a difference. The video we had the kids watch that showed how the scientists tag the animals kind of brought a little bit more for them that it wasn't just a computer game. That really made a difference. (teacher interview response)*

One aspect of the interface that proved to be particularly interesting to students was the human impacts overlay (Halpern et al., 2008), which visually depicts an index calculated from data on a variety of human activities that impact the marine environment, including fishing, climate change, and pollution. Thinking about how the habitats of these marine animals are impacted by certain human activities allowed students to make connections to their own lives, bringing real-world relevancy to their work with *Ocean Tracks*.

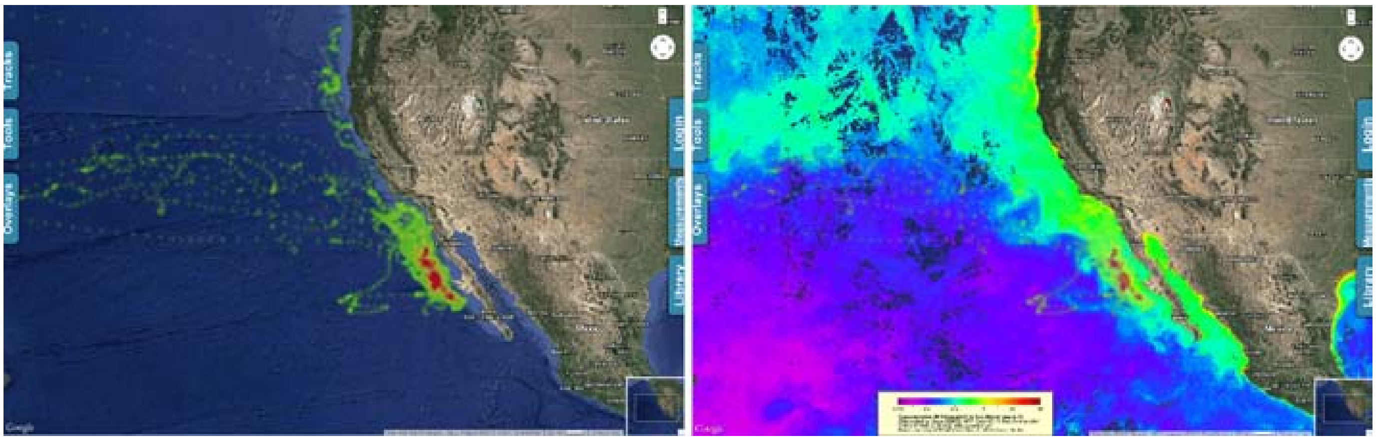
> *I liked the human impact tab because it was interesting to see where in the ocean was impacted the most by us humans because the ocean, especially the Pacific Ocean, is very large and vast. I would be interest[ed] to know how has the human impact changed from 10–20 years ago to now? And how has that affected the animals? (student survey response)*

While students demonstrated successful use of many interface features and tools, our analyses also identified challenges that students faced while working with *Ocean Tracks*. For example, we documented in our screencast recordings 63 instances, lasting from several seconds to a few minutes, when students displayed confusion over use of an interface feature or

FIGURE 5

An example of student work showing how the student was able to use the hotspot tool to identify a habitat hotspot for the bluefin tuna along the coast of California and Baja California (left). The student then used an overlay of chlorophyll (right) to investigate the underlying oceanographic process that created this hotspot. The quote demonstrates how the student was able to integrate their conceptual understanding of upwelling with their interpretation of the data.

> *The chlorophyll levels in this area where the hotspot is are very high…which makes it a very attractive spot for these animals. This hotspot is pretty much right on and right next to the continental shelf, which is a place in the ocean where large amounts of upwelling occur. Also the temperature by the coast is leaning towards the colder side. It stays around 12–16 degrees Celsius, which means since it's colder water there is more upwelling.* (high school student)



tool. In 23 of those instances (37%), students found a specific track function unclear, such as identifying track start and end dates and matching tracks on the track selector to those displayed on the map. In nine instances (14%), slow screen responsiveness due to data-intensive loading times led to student confusion about whether the interface had registered their mouse commands. We also observed six instances when overlapping windows on the screen made it difficult for students to see the data visualizations on the *Ocean Tracks* map or other underlying data views. Data from classroom observations indicate that some students struggled with understanding the relationship between different animal tracks in time, reflecting the complexity of the temporal and spatial nature of the data at hand. Based on analyses of student work assignments and as shown in Figure 4, most students also had trouble with the quantitative aspects of their analyses. They typically presented qualitative descriptions rather than quantitative comparisons of data measures. Future interface and curriculum development efforts will focus on addressing these challenges.

Ocean Tracks: College Edition

Although *Ocean Tracks* was initially designed and tested for high school classrooms, the NSF's recent funding of *Ocean Tracks: College Edition* (OTCE) shows recognition that the data interface and learning resource we have developed have clear potential for widespread use in undergraduate settings. Education research has demonstrated that undergraduate students are not developing robust skills in basic scientific and engineering practices (NRC, 2012b), skills that are key to innovation, discovery, and problem solving. Teaching students to use, analyze, and understand data to explore scientific questions is an essential component of basic undergraduate science education (Manduca & Mogk, 2002), and yet for many students whose undergraduate science courses consist primarily of lectures, reading, and note taking, their success in the course is assessed using standardized tests that emphasize memorization rather than analytical thinking. These approaches are far less effective at motivating students and at developing skills in the practices of science and engineering (PCAST, 2012). Recently, however, undergraduate institutions have begun to adopt approaches to teaching that are grounded in research on learning (NRC, 2015), and there is burgeoning interest in curricula and tools that support more inquiry-based approaches.

Emerging interest in college-level curricula and tools that help teach data skills, promising results from the high school classroom testing, and strong indications of interest from undergraduate faculty led to an NSF award to EDC and the Scripps Institution of Oceanography in the fall of 2014 to develop and test learning modules to support the use of the *Ocean Tracks* interactive map and data analysis tools in college classrooms. The 3-year study involves testing in both community college and university settings and consists of baseline data collection and needs assessment, curriculum development and research, and a pilot study. Research efforts will support curriculum development and investigate how students from diverse institutions engage with online and face-to-face versions of the curriculum materials as well as how these materials improve their understanding of and competence in the use of scientific practices, knowledge of core content, and interest in pursuing careers in science.

Two distinct college-level courses will serve as the test-beds for curriculum development for the OTCE project. The first is an online introductory oceanography course taught at Palomar Community College in San Marcos, California. The second is an upper division undergraduate course taught at University of California San Diego's Scripps Institution of Oceanography, titled "California Coastal Oceanography." Through an iterative curriculum design and research process, we will work collaboratively with our partner faculty members to explore questions including "What supports may be needed to incorporate programs such as *Ocean Tracks* into undergraduate science courses?" and "To what extent do course experiences working with CLIP marine data through *Ocean Tracks* improve undergraduate students' demonstration of scientific practices with data and interest in scientific careers, particularly in the marine sciences?"

Phase 1 of the OTCE project consists of collecting baseline data and conducting a needs assessment to better understand students' prior experience with data and the ways in which oceanography and marine biology faculty use CLIP data sets in their courses. Preliminary findings from student surveys follow.

Student Survey Preliminary Results

As part of the OTCE Phase 1 needs assessment study, we issued a survey (see http://tinyurl.com/ot-ce-survey) to 101 students taking an introductory oceanography course at Palomar College and 181 students taking an introductory course at Scripps on the Earth's water to gauge their

- beliefs about the importance of being able to make sense of data;
- prior experience and confidence levels working with data, data visualizations, and data analysis tools;
- interests and motivations related to the oceans and marine life; and
- academic and career interests (and their connections to data).

The survey response rates for students at Palomar and Scripps were 73% and 77%, respectively. Results from this survey are being used to inform curriculum development, helping us to identify data analysis skills for which students might need the most structured supports, and content areas that will be most engaging and meaningful for students.

Just under two thirds (62%) of total survey respondents from both institutions (n = 214) were female, and one third (33%) said that they know they are interested in pursuing a career in science. To explain why they were taking a course on the oceans, vast majorities of survey respondents agreed or strongly agreed that they have a general curiosity about the oceans (89%), they feel that ocean health and conservation are important to them (81%), and they are concerned about the effects of climate change on the oceans (80%). Similarly, high proportions of survey respondents also agreed or strongly agreed that they believe it is important to know how to make sense of data to get a good job (86%), to be successful in whatever career they choose (86%), and to be a more effective and informed citizen (91%).

Conclusions

New technologies deployed in the oceans are generating unprecedented quantities of data, illuminating previously unknown environments, and enabling the exploration of whole new types of questions. This same revolution is happening beyond the realms of marine science in diverse applications ranging from law enforcement to agriculture. To realize the full potential of big data to answer questions, improve processes, and solve problems, our schools should be preparing students with a new set of workforce skills. Furthermore, beyond tomorrow's workforce, it is imperative that all citizens are able to make informed, evidence-based decisions in a big data world.

The *Ocean Tracks* project was developed to find ways to bring the potential benefits of new tools of ocean exploration to a much broader audience. Preliminary results from our studies with high school students suggest that this approach shows promise in promoting student skills in scientific practices with CLIP data and interest in data and/or marine science, and our early work with undergraduate college students suggests an equally high level of interest and receptiveness to this approach. Looking forward, the goal is to determine how to build on this early success and use the *Ocean Tracks* platform, as well as the principles on which it was developed, to help improve the use of data in science education more broadly.

Our experiences over the past 5 years on four NSF-funded projects have convinced us that there is tremendous untapped potential in the large scientific data sets that are increasingly available to anyone with an Internet connection. We have also learned that there are many challenges associated with making these data truly accessible to novice users. We need to continue to find ways to make a variety of data accessible via novice-friendly interfaces and data analysis tools. We need to better understand the skills necessary to prepare students for a big data world, and we need to develop effective ways to teach these skills over the course of a student's schooling. We need to develop new types of training programs for teachers. Tackling these challenges via *Ocean Tracks* has required the active, day-to-day engagement of a highly multidisciplinary team that includes high school and undergraduate educators, curriculum developers, education researchers, marine biologists, and technology developers. Just as our collaboration has engaged those with diverse expertise and perspectives, we believe raising a generation equipped to unlock the potential of big data will require the sustained and coordinated efforts of those with expertise in education, science, and technology, compelling new types of conversations and collaborations that cross disciplinary boundaries.

Corresponding Author:

Randall E. Kochevar
Education Development Center, Inc.
43 Foundry Avenue
Waltham, MA 02453
Email: rkochevar@edc.org

References

Block, B.A., Jonsen, I.D., Jorgensen, S.J., Winship, A.J., Shaffer, S.A., Bograd, S.J., … Costa, D.P. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature. 475:86-90. http://dx.doi.org/10.1038/nature10082.

Dijcks, J. 2013. Oracle: Big Data for the Enterprise. http://www.oracle.com/us/products/database/big-data-for-enterprise-519135.pdf.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., … Watson, R. 2008. A global map of human impact on marine ecosystems. Science. 319:948-52. http://dx.doi.org/10.1126/science.1149345.

Hazen, E.L., Jorgensen, S., Rykaczewski, R.R., Bograd, S.J., Foley, D.G., Jonsen, I.D., … Block, B.A. 2012. Predicted habitat shifts of Pacific top predators in a changing climate. Nat Clim Change. 3:234-8. http://dx.doi.org/10.1038/nclimate1686.

Hotaling, L. 2005. The Gulf Stream voyage: Using real time data in the classroom. Mar Technol Soc J. 39(4):90-5. http://dx.doi.org/10.4031/002533205787465841.

Krumhansl, R., Peach, C., Foster, J., Busey, A., & Baker, I. 2014. Visualizing Oceans of Data: Educational Interface Design. Waltham, MA: Education Development Center, Inc. Available from http://oceansofdata.org/our-work/visualizing-oceans-data-educational-interface-design

Manduca, C.A., & Mogk, D. 2002. Final report on an interdisciplinary workshop held at Carleton College. Available from http://serc.carleton.edu/files/usingdata/UsingData.pdf.

Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., & Byers, A.H. 2011. Big Data: The Next Frontier for Innovation, Competition, and Productivity. McKinsey Global Institute. http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation.

Maxwell, S.M., Hazen, E.L., Bograd, S.J., Halpern, B.S., Breed, G.A., Nickel, B., … Costa, D.P. (2013). Cumulative human impacts on marine predators. J Nat Comm. 4(2688):1-9. http://dx.doi.org/10.1038/ncomms3688.

National Research Council. 2000. Front Matter. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Washington, DC: The National Academies Press.

National Research Council. 2012a. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.

National Research Council. 2012b. Discipline-based education research: understanding and improving learning in undergraduate science and engineering. In: Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research, eds. Singer, S.R., Nielsen, N.R., & Schweingruber, H.A., 1-31. Washington, DC: The National Academies Press.

National Research Council. 2015. Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. Washington, DC: The National Academies Press.

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Oceans of Data Institute. 2014a. Profile of a big-data-enabled specialist. Waltham, MA:

Education Development Center, Inc. Retrieved from http://oceansofdata.org/our-work/profile-big-data-enabled-specialist.

Oceans of Data Institute. 2014b. Profile of a big-data-enabled specialist: Executive summary. Waltham, MA: Education Development Center, Inc. Retrieved from http://oceansofdata.edc.org/sites/oceansofdata.org/files/ODI%20Panel%20Exec%20Summary_FINAL.pdf.

Parsons, C. 2006. SWMP/IOOS Real-Time Data in K-12 Classrooms: A Front-End Evaluation (NOAA/Estuarine Reserves Division). Monterey, CA: Word Craft. Available from http://coseenow.net/files/2008/12/rtd_fullreport.pdf

President's Council of Advisors on Science and Technology. 2012. Engage to Excel: Producing one million additional college graduates with degrees in science, technology, engineering and mathematics. Report to the President.

Shaw, J. 2014. Why "Big Data" is a big deal: information science promises to change the world. J Harvard Mag. 3 (2014):30-5.

Simmons, M.E., Wu, X.B., Knight, S.L., & Lopez, R.R. 2008. Assessing the influence of field- and GIS-based inquiry on student attitude and conceptual knowledge in an undergraduate ecology lab. J CBE Life Sci Educ. 7(3):338-45. http://dx.doi.org/10.1187/cbe.07-07-0050.