VISUALIZING OCEANS OF DATA

Ocean Tracks

A CASE STUDY

EDUCATION DEVELOPMENT CENTER, INC • SCRIPPS INSTITUTION OF OCEANOGRAPHY • STANFORD UNIVERSITY

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OCEAN TRACKS: A Case Study

VISUALIZING OCEANS OF DATA • EDUCATIONAL INTERFACE DESIGN

I. INTRODUCTION

In 2012, the Oceans of Data team at EDC published *Visualizing Oceans of Data* (Krumhansl, Peach, Foster, Busey, and Baker, 2012), which communicated the findings of a two-year NSF-funded study that gathered knowledge relevant to the design of educational interfaces to large online scientific data sets. Drawing on expertise from diverse fields such as cognitive psychology, cartography, mathematics education, visual perception, and computer science, we developed guidelines for interface design that we hoped would open the doors to student exploration of the natural world using the exciting array of authentic scientific data that are now available to anyone with a computer and Web access.

Several years ago, when we presented the Oceans of Data advisory board with a draft of *Visualizing Oceans of Data* and the guidelines therein, several of them commented that this ideally would be a "living document." This is because the online availability of large scientific data sets was a relatively recent and rapidly growing phenomenon. Aside from the work of a few pioneers who recognized early on the importance of bringing authentic data into the classroom (Hotaling, 2005; Hotaling, Matsumoto, and Herrington, 2006; Ledley, Dahlman, Domenico, and Taber, 2005; Ledley, Prakash, Manduca, and Fox, 2008; Manduca and Mogk, 2002), little researched and documented experience existed in engaging students with these online data. We knew without doubt that as the education community gained experience, new insights would refine our thinking about the guidelines, adding new ones and rendering others obsolete. It is in that spirit that this case study was written.

Indeed, as we were reviewing and compiling the knowledge that was the basis for the guidelines, we were actively developing a vision of a program that would apply the guidelines to the development and testing of a student-friendly interface. In 2012, NSF funded us to do so via *Ocean Tracks: Marine Migrations in a Changing Ocean.* As we've engaged with the Ocean Tracks work, we've grappled with many challenges and learned lessons that have given us a deeper understanding of what it takes to bring professionally collected data sets to students in meaningful ways. The development of this addendum has been an opportunity to reflect on our learning and update our thinking about the *Visualizing Oceans of Data* guidelines for educational interface design. And although our exploratory work on Ocean Tracks has focused primarily on development of the interface, we've also learned critical lessons from our pilot testing in high schools about the types of supports beyond the interface—e.g., curriculum and teacher professional development—that are essential elements of the endeavor. In addition, we've embarked upon a curriculum-focused project just funded by NSF in the fall of 2014—Ocean Tracks: College Edition, and our Ocean Tracks team is actively working with Concord Consortium on developing and classroom testing new analytical tools via the *Common Online Data Analysis Platform* (CODAP) project.

It's worth noting that since *Visualizing Oceans of Data* was written, recognition of the need for "big data" skills both in science and beyond has exploded. References to how data are being used in broad ranging applications, from controlling epidemics to solving homicides, are in the daily news. Employers are lamenting the lack of professionals with skills in working with these large, complex data sets, and universities and community colleges are scrambling to create degree and certification programs to prepare students with the needed workforce skills. The recently released *Next Generation Science Standards* place an unprecedented emphasis on developing students' ability to use data to make evidence-based decisions (Kastens, 2015; NGSS Lead States, 2013). Students also show that they recognize the importance of developing their ability to make meaning from data. In a recent survey of over 280 college students, conducted by the Oceans of Data Institute (oceansofdata.org), 85% of respondents from a community college and an elite four-year undergraduate institution agreed or strongly agreed that the ability to make sense of data is important to get a good job and will help in their future careers. An overwhelming 90% of respondents agreed or strongly agreed that learning to make sense of data will help them be more effective and informed citizens.

In sync with this growing recognition of the importance of data skills, there has been accelerating investment in education research and development focused on building students' ability to make meaning of real-world complex data sets. While we've been involving students in exploring data from tagged marine animals via Ocean Tracks, other projects have, for example, engaged students in using data from starlight to detect exoplanets, NASA satellite data to investigate regional and global climate, and earthquake data to explore plate tectonic boundaries and geological hazards (Other Worlds/ Other Earths: cfa.harvard.edu/smgphp/otherworlds/OW/index.php; Data-enhanced Investigations for Climate Change Education

(DICCE): dicce.sri.com/; Environmental Literacy and Inquiry Project (ELI), ei.lehigh.edu/eli/tectonics/overview.html). It's beyond the scope of this writing effort to capture the lessons learned from these and other fascinating and important projects. Rather, this addendum is intended to contribute what we've learned from our Ocean Tracks projects to the larger body of knowledge about building data literacy that is actively being constructed by the education research community.

Development of the Ocean Tracks Case Study

This case study was developed with the intention of conveying useful information to practitioners who are developers of educational interfaces to online scientific data sets. As such, it has not been presented as an academic presentation of research findings but, rather, focuses on sharing the experiences and expertise our team acquired while endeavoring to apply guidelines articulated in *Visualizing Oceans of Data*. Thus, the reflections contained within this addendum draw heavily on transcripts from a series of team discussions focused on illuminating and evaluating the design principles we applied while developing and piloting the Ocean Tracks interface and supporting curricula in high schools. Although we gained tremendous insights from our high school pilots conducted in 2013 and the data analyses we completed in 2014, it should be noted that we are continuing to build experiences through our Ocean Tracks: College Edition and CODAP projects; and though this document focuses on our work with high school classes, our work is active and ongoing, and our learning curve continues to be steep.

Organization of This Addendum

To highlight the key lessons learned from our rich and complex Ocean Tracks experiences, we didn't write this as a comprehensive review of all of the guidelines in *Visualizing Oceans of Data* but, rather, we feature in this addendum the guidelines that emerged as the most relevant and important to engaging students with the Ocean Tracks data and curriculum. We've also devoted space to conveying valuable lessons we've learned from designing curriculum and working with teachers to support the use of the Ocean Tracks interface in the classroom, and from working as an interdisciplinary team.

The remainder of the addendum is organized as follows:

SECTION 2. THE DEVELOPMENT OF OCEAN TRACKS

We began developing our vision for the Ocean Tracks interface nearly a year before we won our first grant to support its creation, and then worked intensively through two rounds of pilot testing to produce the interface and curriculum supports. This section describes the key steps in our development process.

SECTION 3. THE OCEAN TRACKS INTERFACE

This section provides an orientation to the Ocean Tracks interface, including a description of key features and functionality.

SECTION 4. APPLYING THE VISUALIZING OCEANS OF DATA GUIDELINES TO THE OCEAN TRACKS INTERFACE

This section describes how we endeavored to optimize cognitive load and address specific guidelines about data access and the design of data visualization, and what we learned from our efforts.

SECTION 5. BEYOND THE INTERFACE

To support sustained student engagement with the Ocean Tracks interface during pilot testing, we put considerable effort into designing curricula, teacher supports, and process management supports. This section conveys what we did and what we learned from these experiences.

SECTION 6. SUCCESSFUL PARTNERSHIPS FOR INVOLVING STUDENTS WITH PROFESSIONAL SCIENTIFIC DATA

Ocean Tracks was created by an interdisciplinary team of education experts, scientists, and software developers, and we feel that our collaborative work has been foundational to our success. This section communicates the lessons learned from working together that we feel will benefit others engaged in similar endeavors.

2. DEVELOPMENT OF THE OCEAN TRACKS INTERFACE

The Ocean Tracks team has gathered intelligence about how to design student interfaces to scientific data, as well as curriculum and teacher supports, via a number of activities. These activities, as well as key aspects of our approach, are summarized in this section.

Early Development

The idea for Ocean Tracks developed over many months, in parallel with our work on the *Visualizing Oceans of Data* guidelines. The spark was generated in November 2010 at the *Workshop to Define Student Collaborative Climate Research*, sponsored by NOAA and NSF (Boger, Ledley, McLaughlin, & Michalopoulos, 2010), when the lead investigator of the Oceans of Data study (and Ocean Tracks) and Diane Stanitski, a scientist with NOAA's Climate Program Office, were introduced and tasked with developing and presenting a program design at the workshop that would engage students in research with online scientific data sets. This spurred a series of deeply interesting and productive conversations that extended well beyond the workshop and soon involved others with expertise in marine biology and teaching. We consulted with scientists and conservation organizations, reviewed literature about current scientific studies, and explored the range of fascinating data sets available, including the Tagging of Pacific Predators (TOPP) data, which became the centerpiece of our Ocean Tracks interface. As we developed and deepened our thinking about Ocean Tracks, two other things were happening in the world around us that validated the importance of the idea we were developing—the awareness of big data as an unprecedented resource for data-driven inquiry and problem solving was exploding, and (in the education realm) the *Next Generation Science Standards* was being developed, which greatly elevate the importance of using data in the science classroom (Kastens, 2015).

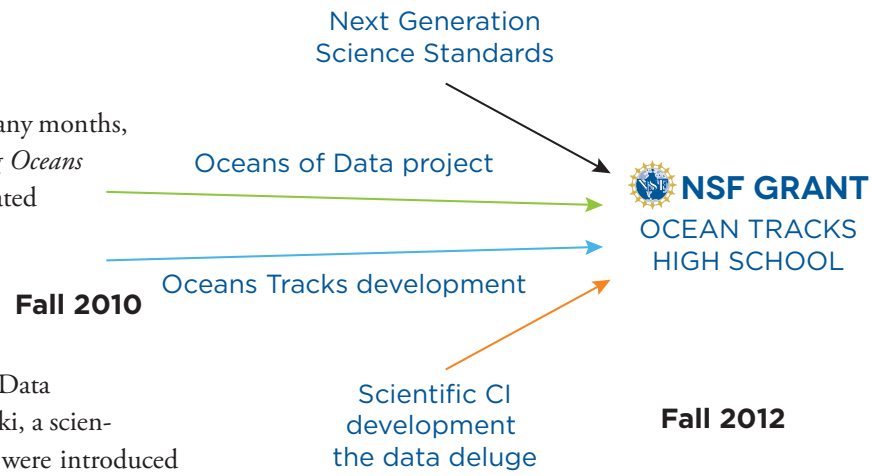


Figure 1. Simultaneous developments in science education, data infrastructure and availability, and research partnerships around teaching and learning with data provided inspiration and impetus for Ocean Tracks, which was initially funded through an NSF DRK-12 grant in fall of 2012.

In the fall of 2012, NSF funded *Ocean Tracks: Investigating Marine Migrations in a Changing Ocean*, a collaboration between EDC and Stanford University, which enabled the development of the Ocean Tracks interface and testing in high school classrooms. Our proposed approach focused on enabling students to explore current and compelling scientific questions by providing them with a customized set of data and analytical tools via an interface designed using *Visualizing Oceans of Data* guidelines, supported by guiding curricula and teaching supports.

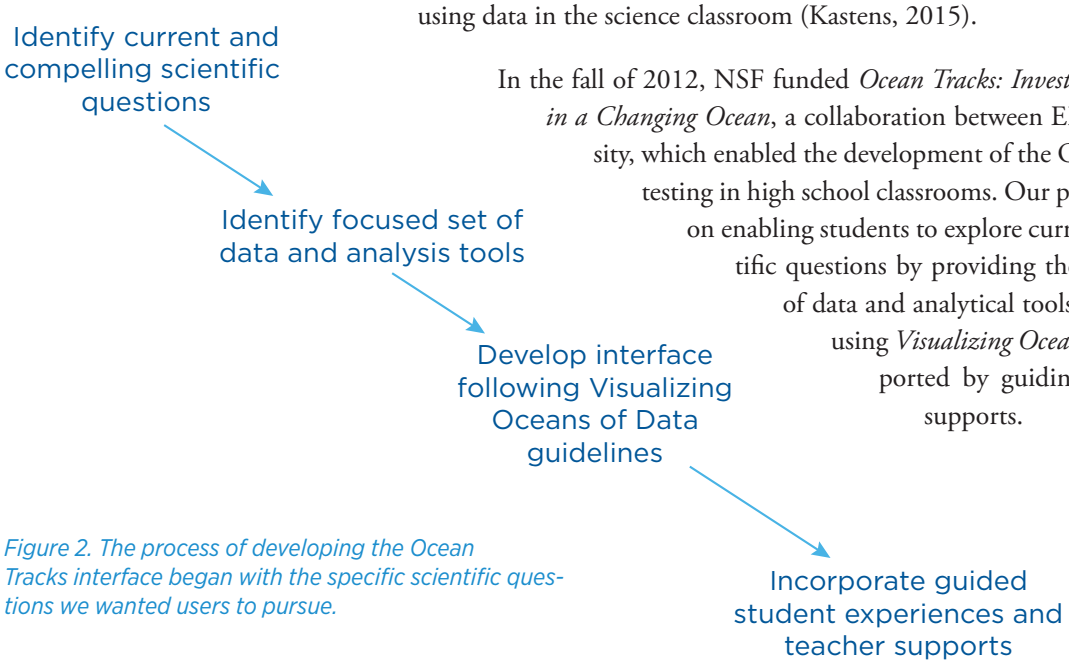


Figure 2. The process of developing the Ocean Tracks interface began with the specific scientific questions we wanted users to pursue.

Development and Testing of Pilot 1 and Pilot 2 Versions

Activities in 2013 and 2014 focused on rapid, iterative development of the interactive Web interface, along with supporting curricula, teacher supports, library content, and video tutorials. The development process was informed by intensive interactions with students and teachers during two rounds of pilot testing. The following are key elements of our process and products:

OUR GOAL, established early on, was to create an interface that allowed students to get quickly to the data and do the same type of analyses as those performed by scientists working with these data sets. We endeavored to provide a data set that was constrained sufficiently to allow students to find meaningful and interesting patterns without too much difficulty, but that also allowed them sufficient freedom to explore a range of scientific questions, including those that they developed on their own.

OUR TEAM, including scientists, data providers, curriculum developers, education researchers, and software developers, has worked collaboratively from the inception of Ocean Tracks work (see Exhibit 1). This involved not only a face-to-face kick-off meeting to develop priorities and establish a timeline and work assignments, but also weekly virtual videoconferences to share progress, hone our approach, and make decisions. Our advisory board, which included experts in technology-enhanced learning, data visualization, marine biology, and oceanography, provided critical advice at key junctures during Ocean Tracks development.

OUR PRODUCT included not only the Ocean Tracks data interface and analytical tools, but also curriculum modules that guided students in how to use the data and tools as scientists do, and a customized library of background information about the data and relevant science concepts. In the Pilot 1 version, we integrated a student notebook into the interface that allowed students to record data and ideas, and attempted to help them structure their scientific thinking.

OUR CLASSROOM TESTING involved two rounds of user testing with small groups of high school students: Pilot 1 testing with 61 students in three high school classrooms and Pilot 2 testing with the same three high school teachers plus a fourth (a total of 134 students). Researchers collected data through classroom observations, audio recordings, screen recordings, samples of student work, student surveys, student focus groups, and teacher logs. All members of the Ocean Tracks team (education researchers, scientists, and the software developer) participated in classroom observations during the pilots, which occurred simultaneously in the 3–4 classrooms, with each class engaging primarily with Ocean Tracks over a period of 5–6 weeks. The goal of the pilot tests was to gather data relevant to the following research questions:

- *What difficulties do students encounter when navigating the website and using the data visualizations and written materials?*
- *What initial indications do we have that the interface allows students to engage in authentic scientific practices?*

Between Pilots 1 and 2, the data were analyzed qualitatively, with all team members participating, to identify successes and challenges and find patterns across data sources. Based on this analysis, the team and a subset of advisors developed and reviewed a list of needs at a face-to-face meeting and generated ideas about ways to meet these needs. These activities resulted in modifications to the interface, the development of a new set of curriculum modules, and a stronger emphasis on teacher support. With supplemental funding, the team also launched production of a set of multimedia materials to support students in using the Ocean Tracks interface. These included video tutorials demonstrating how to use the tools and resources on the interface, a series of video interviews with scientists, and a five-minute video providing background information on how the data were collected in the field and processed for display on the interface.

OUR EVALUATION ACTIVITIES focused on developing a better understanding of the types of supports teachers need to facilitate productive use of the Ocean Tracks interface in high school classrooms. The evaluation included two studies: (1) evaluation of the Ocean Tracks interface by non-pilot teachers and (2) feedback on Ocean Tracks by pilot teachers.

Exhibit 1: Ocean Tracks Collaborators Team

OCEAN TRACKS TEAM

Ruth Krumhansl: *Principal Investigator (PI), Founder, Oceans of Data Institute, EDC*
As lead PI of the Oceans of Data, Ocean Tracks and Ocean Tracks: College Edition (OTCE) projects, Ruth Krumhansl brings her rich background as a scientist, curriculum developer, high school teacher, and in education research and development to her leadership of the Ocean Tracks program. She has been responsible for overall technical direction of the projects and works in close collaboration with staff leads on all strands of work including research, curriculum, science, software development, evaluation, and project management.

Randy Kochevar: *Co-Principal Investigator (Co-PI), Director, Oceans of Data Institute, EDC*
Initially joining the Ocean Tracks team from Stanford University, Randy Kochevar brings experience in scientific research, science communication and informal education to the Ocean Tracks and CODAP projects. He provides content expertise on the animal tracking data, and as Stanford liaison, facilitated access to the TOPP data. He also serves as the technical liaison with EarthNC, the technology partners, based on his experience in developing Web interfaces for animal telemetry data. He currently works with the PI and Project Director to lead all aspects of the Ocean Tracks: College Edition project.

Cheryl Peach: *PI, Director, Scripps Education Alliances, Scripps Institution of Oceanography*
Cheryl Peach, collaborating PI of both the Oceans of Data and Ocean Tracks: College Edition projects, brings many years of experience in ocean science and education outreach to the team. She has served as primary liaison between Scripps and EDC, hosting and participating in project meetings and doing classroom observations, and has been instrumental in dissemination activities.

Christine Brown: *Co-PI, Project Director, EDC*
Christine Brown served as co-PI and project director of Ocean Tracks during the development and pilot testing of Ocean Tracks in high schools. She assisted the PI in project management and oversaw budget and personnel issues. Brown brought her experience in curriculum development to the direction of the curriculum and teacher support components of the project and served as a liaison between the curriculum and technology teams.

Josephine Louie: *Co-PI, Project Director, Research Program Lead, EDC*
Since January 2014, Josephine Louie has been serving as co-PI and project director of Ocean Tracks and Ocean Tracks: College Edition. She has been leading the research program for both projects, including analyses of high school pilot test data and the development of assessments and qualitative and quantitative research activities associated with Ocean Tracks: College Edition. She coordinates and directs the work of our interdisciplinary team, facilitating team meetings, and overseeing the budget and timeline.

Jacqueline DeLisi: *Co-PI, Research Program Lead, EDC*
Jacqueline DeLisi directed the piloting of Ocean Tracks in high schools during 2013, designing and directing data collection activities during the high school classroom pilots, performing qualitative analyses of pilot data, and serving as primary liaison with the outside evaluator.

Amy Busey: *Oceans of Data Liaison, Research Program Lead, EDC*
As Oceans of Data liaison, Amy Busey has contributed expertise regarding Oceans of Data findings to all aspects of the Ocean Tracks work. As a research program lead, she organized and implemented data collection activities during the two high school pilot tests. Busey is also leading the Ocean Tracks team on the Common Online Data Analysis Platform project.

Kira Krumhansl: *Science Coordinator, Marine Biologist, EDC*
Kira Krumhansl has overseen scientists' participation in the project, coordinated scientific review of project content, developed curriculum modules for both high school and college, and developed scientific background materials and videos for the Ocean Tracks library. She has also participated in data collection and data analyses during the high school pilot tests and Ocean Tracks: College Edition research activities.

Julianne Mueller-Northcott: *Lead Teacher Partner, EDC; Science Teacher, Souhegan High School*
Julianne Mueller-Northcott has contributed her expertise and classroom experience as a practicing high school teacher to the development and testing of the Ocean Tracks interface, curriculum, and support materials for both the high school and college projects. In addition to her role developing curriculum as a member of the Ocean Tracks team, she has piloted the Ocean Tracks and Common Online Data Analysis Platform project materials in her own marine biology courses.

Brad Winney: *Interface and Business Development Lead, Co-founder, CEO, EarthNC*
Brad Winney managed the development of the Ocean Tracks interface. He has also played a key role in advising the team on intellectual property issues, as well as business development considerations.

Virgil Zetterlind: *Lead Software Developer, Co-founder, CTO, EarthNC*
Virgil Zetterlind has been the technical backbone of the Ocean Tracks interface, overseeing all aspects of design, development, production, testing, and refinement. Zetterlind has also provided as-needed classroom support (e.g., creating usernames and passwords for classroom tests) and has participated in all aspects of the project, including classroom observations and analysis.

Jessica Sickler: *Evaluator, Senior Research Associate, Lifelong Learning Group (LLG)*
Jessica Sickler directed LLG's evaluation activities on the Ocean Tracks project as a complement to the research component being led by EDC. The evaluation examined the extent to which the project achieved its goals with a focus on assessing the effectiveness of the implementation of the Ocean Tracks model by teachers.

Erin Bardar: *Curriculum Developer, EDC*
Erin Bardar has been leading the curriculum development team on the Ocean Tracks: College Edition project. She was also involved in developing and administering student surveys and in the review of undergraduate textbooks for the research program's Year 1 baseline studies.

Silvia LaVita: *Project Coordinator, EDC*
Silvia LaVita has been providing the Ocean Tracks team with project support such as meeting planning and logistics, accounting processing, website design, and formatting and editing.

Lihini Aluwihare: *Faculty Partner, Professor, Scripps Institution of Oceanography*
Lihini Aluwihare is working with EDC curriculum experts to identify ways in which Ocean Tracks can be incorporated into undergraduate science classrooms. This has involved working with others on the team to develop curriculum modules, and pilot testing them in her classes.

Al Trujillo: *Faculty Partner, Professor, Palomar Community College*
Al Trujillo is working with EDC curriculum experts to develop learning goals appropriate to community colleges courses, along with curriculum modules to be tested in his classes, which are taught almost exclusively online.

OCEAN TRACKS ADVISORY BOARD

Diane Stanitski, Climatologist and Program Officer, NOAA Climate Programs Office, was a key contributor to the development of the vision for Ocean Tracks. In addition to her scientific responsibilities at NOAA, she has served as climate science consultant for The GLOBE program and NOAA host researcher for The JASON Project.

Rick Lumpkin, Oceanographer, NOAA Atlantic Oceanographic and Meteorological Laboratory, acts as scientific director of the Global Drifter Program, a system of satellite-tracked surface drifting buoy observations that are incorporated in the Ocean Tracks interface.

Lin Chambers, Physical Scientist and Education and Public Outreach lead at NASA Langley Research Center, she engages students in NASA earth science research through the My NASA DATA and CERES S'COOL projects.

Chris Quintana, Assistant Professor of Education, University of Michigan, is an expert in the design of software supports to scaffold students' scientific work.

Alan MacEachren, Geography Professor at Pennsylvania State University and Director of the GeoVISTA Center, is author of *Geovisualization and How Maps Work,* and has expertise in data visualization and visual analytics, cartography, and cognitive science.

Peter Etnoyer, Marine Biologist with NOAA's Center for Coastal Ocean Science, is the author of many scientific articles documenting habitat hotspots in the Pacific Ocean.

Shaun Dolk, Manager of the Drifter Operations Center for NOAA's Atlantic Oceanographic and Meterological Laboratory, manages satellite-tracked surface drifting buoy observations worldwide.

Stephen Bograd, Director of NOAA Fisheries Service, NOAA Southwest Fisheries Science Center, has expertise in the electronic tagging of animals, physical oceanography, and physical-biological interactions.

Elliott Hazen, Research Ecologist, NOAA Southwest Fisheries Science Center, studies animals' habitat use and preferences based on mathematical modeling of their behavior.

Kim Kastens, Research Professor, Lamont-Doherty Earth Observatory of Columbia University and EDC Distinguished Scholar, contributed expertise in student understanding of geospatial data and the development of scientific thinking.

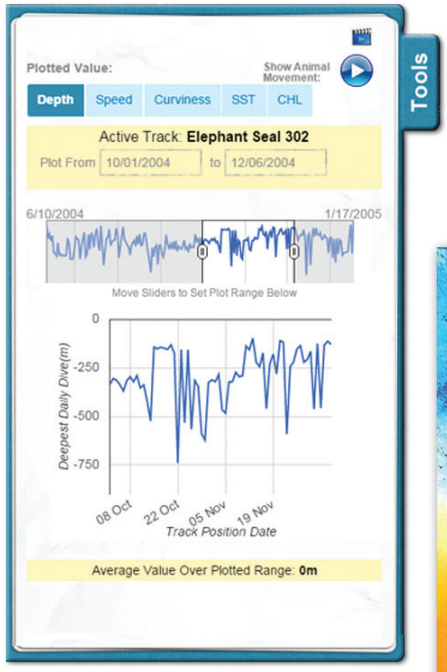
Bill Finzer, Senior Scientist, KCP Technologies and Concord Consortium, was lead developer of the Fathom Dynamic Data™ Software, Data Games, and CODAP, which provide software tools to support students' work with data. Finzer served as a senior advisor to Ocean Tracks, contributing expertise in software and curriculum development and research on learning statistics.

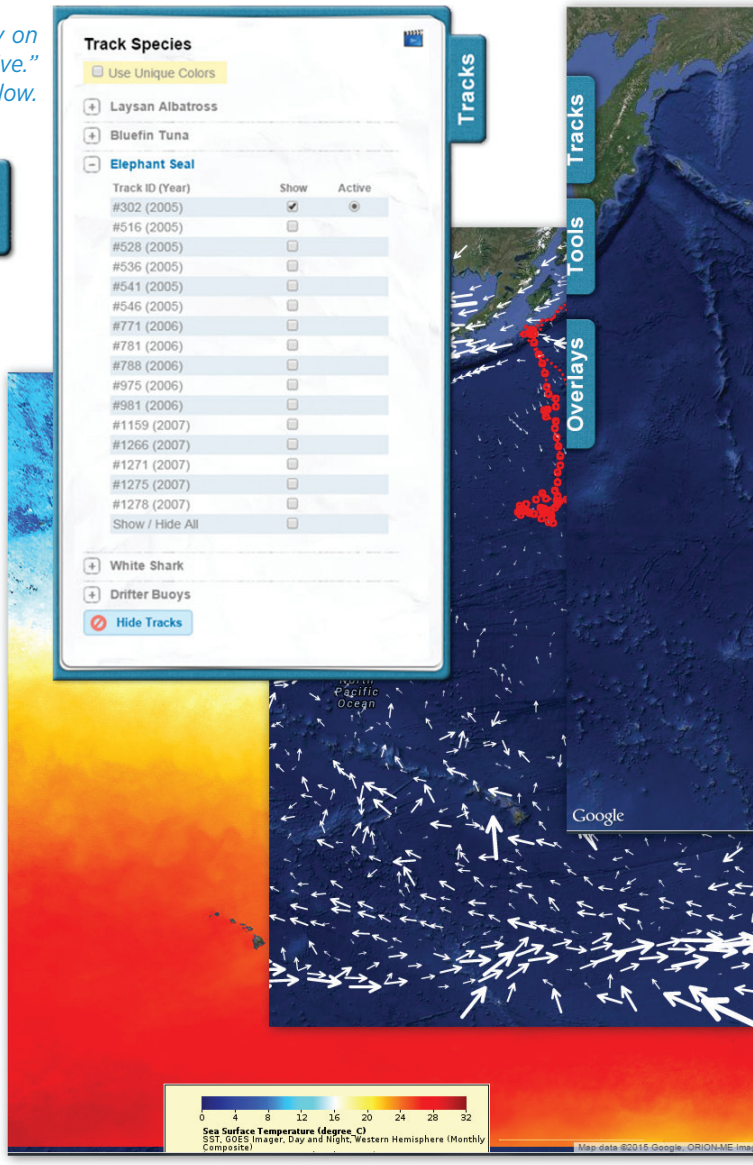
3. THE OCEAN TRACKS INTERFACE

Visualizing Oceans of Data identifies three different possible approaches to building a student interface to professional scientific data sets. Two of them involve working with an existing expert interface, either building student supports "on top of" and/or writing curriculum that explain the steps students should follow to interact with an expert interface. The Ocean Tracks project followed a third approach, which was strongly recommended by the Oceans of Data authors and members of its advisory board: building a brand new interface focused on student users.

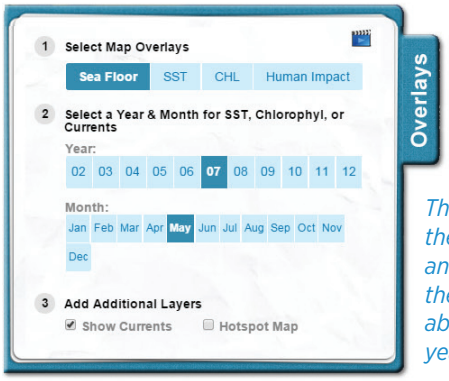
The Ocean Tracks map interface is the core of the Ocean Tracks learning experience, and has been the focus of our ongoing development efforts. When one accesses the Ocean Tracks Map Interface, either by clicking on the map image on the

The Tracks tab allows users to select which tracks to display on the map, and to determine which one of those tracks is "active." Data from the active track are accessible in the "Tools" tab below.





The Tools tab allows users to display additional time series data from whichever track is "active." Data selections include maximum daily depth, average speed, track curviness, sea surface temperature and chlorophyll-a along the track. Data for the entire duration of the track is displayed in the upper graph, and the lower graph provides a more zoomed-in view.



The Overlays tab allows the user to display different data layers over the map, including batnymetry, satellite sea surface temperature and chlorophyll-a, human impacts, currents or hotspots (based on the tracks they have selected.) Because some environmental variables are constantly changing, users can also select the month and year for sea surface temperature, chlorophyll-a, or currents.

oceantracks.org home page (which also includes background information about the program and resources to support its use) or by accessing it directly at oceantracks.org/map/, the user is presented with a single animal track overlaid on a familiar Google Maps satellite view centered on the North Pacific Ocean (see Figure 3). This view includes navigation tools that are broadly familiar to Web users, including the ability to pan around the map by clicking and dragging, as well as zooming in and out to view features of interest.

On the left and right margins of the map are pull-out tabs that allow users to access a variety of tools they can use to explore more deeply the behaviors of the animals and the environments they inhabit. Aside from the overview of these tools in Figure 3, we would encourage readers to go online to try them yourself.

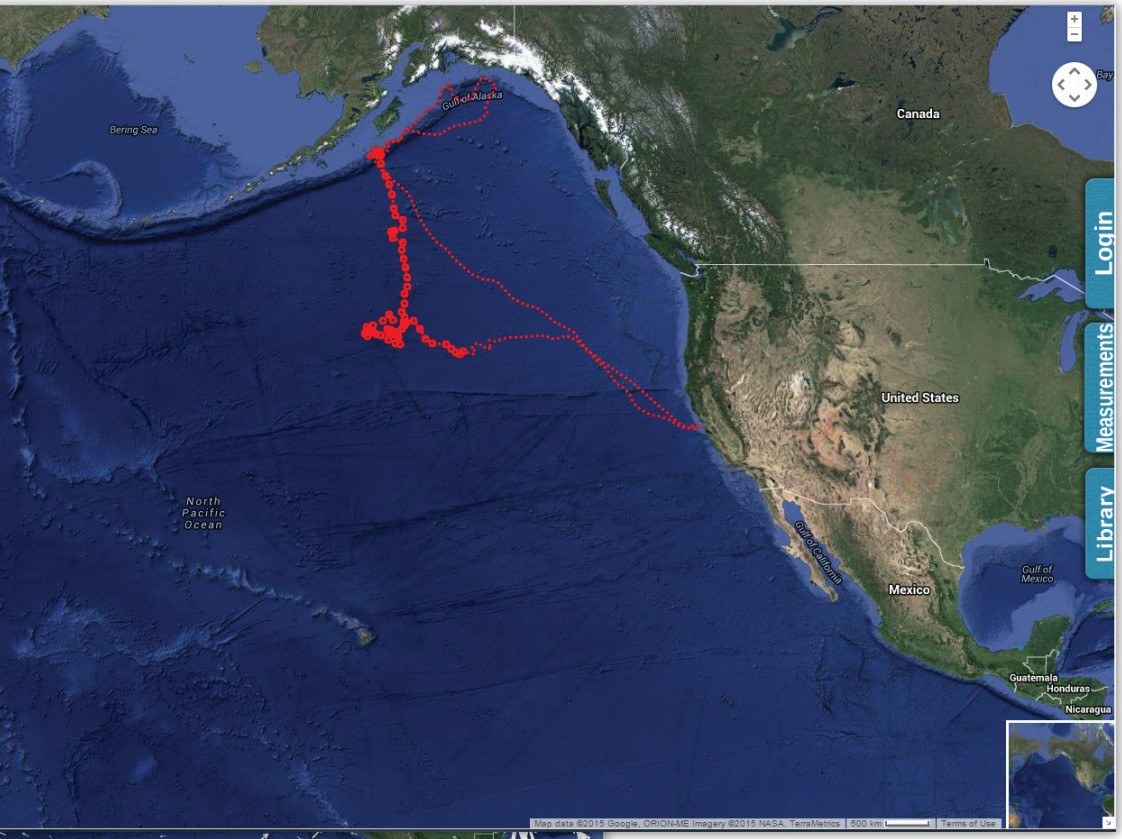
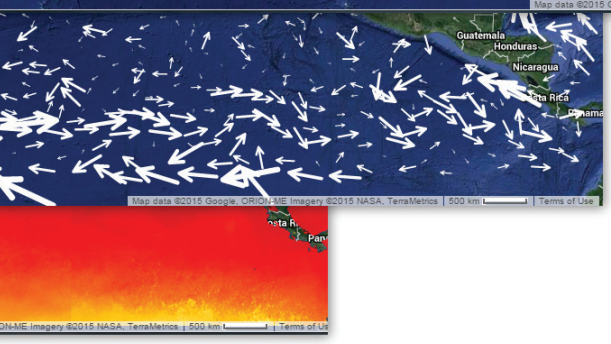


Figure 3. The Ocean Tracks map interface includes a variety of tools that can be accessed from pull-out tabs along the sides of the map.



The Library tab provides users with access to additional information specifically relevant to Ocean Tracks, including text, photos, illustrations and videos.

4. APPLYING THE *VISUALIZING OCEANS OF DATA* GUIDELINES TO THE OCEAN TRACKS INTERFACE

When developing the Ocean Tracks map interface, we focused primarily on applying guidelines that are presented in three of the sections of *Visualizing Oceans of Data:* Accessing Data, Geo-referenced Data Representations, and Animations. Not surprisingly, as we created, tested, and revised the interface, we found it wasn't practical or appropriate to apply all of the specific guidelines. We also found that some of those we did apply were more critical than we had realized and others not as important in the context of Ocean Tracks.

The need to optimize cognitive load for student users drove in a fundamental way all of our decisions about how to design the interface (see Key Underpinnings: Cognitive Load Theory in *Visualizing Oceans of Data*). Cognitive load plays a pivotal role in shaping a user's experience in a data interface, where tasks and concepts that have significant complexity (intrinsic cognitive load) require that developers minimize the cognitive resources required to interpret how the information is presented (extraneous cognitive load) and maximize the resources devoted to activating and building on prior knowledge (germane cognitive load). The cognitive load that students experience is closely related to two other key underpinnings discussed in *Visualizing Oceans of Data*: visual perception (mechanisms and biases of the human visual system) and schemata (mental frameworks for processing information). An effective interface design reduces extraneous cognitive load by working *with* our visual processing systems as well as scaffolding students whose frameworks related to working with data are still developing.

Because the *Visualizing Oceans of Data* guidelines are each designed to optimize cognitive load in ways that are all in service of enabling student access and inquiry with scientifically collected data, in most cases it is difficult or impossible to attribute students' success to a single design element or strategy. Instead, we begin our discussion of the guidelines by noting the many successes we observed in students' interactions with the interface and their use of the data and tools to develop ideas and questions about animals' behavior in the ocean environment.

- *Students were immediately successful in navigating the features of the interface and manipulating data displays.* We observed students manipulating the map and the graph (in the Tools tab) to view tracking data within the first few minutes of engagement with the interface with little or no instruction. They showed familiarity with the Google Maps interface, zooming in to observe details and panning around the map.
- *Students were able to easily access and display data.* Students were able to display and interact with different tracks on the map and graph within the first class period, and most students (when allowed to freely explore) were observed turning on and off the various overlays.
- *Interactions with the interface were generally fluid and intuitive.* By the end of their experience with Ocean Tracks, students were quite adept at creating track, graph, and overlay displays using the range of available data sets.
- *Students used the Ocean Tracks visualization and analysis tools to develop their ideas about animals' behavior and the environment.* Within a few minutes of being introduced to Ocean Tracks, we observed students asking questions spurred by their interactions with the interface, for example, about why animals were traveling to certain parts of the ocean and what they were doing there. Reviews of student work showed that students were able to utilize the graphed data, hot spot maps, and overlays to relate patterns in habitat usage to physical processes in the ocean environment. Data also indicated that students were relating multiple variables to each other and generating hypotheses about what the data indicated about animal behavior.

The discussions that follow include brief overviews of considerations associated with Accessing Data, Geo-Referenced Data Representations, and Animations, with a focus on those most relevant to Ocean Tracks. Then, we describe how we implemented the associated guidelines in Ocean Tracks, and what we learned from our efforts.

Accessing Data

A data access portal intended for student users should have a simple goal—it should make it easy for students to see the data that are available, and to explore, think about, and generate questions about these data.

p. 49, Visualizing Oceans of Data

The guidelines relating to Accessing Data in *Visualizing Oceans of Data* were written in recognition of the fact that, for students, working with professionally collected scientific data is hard, and the first barrier they encounter is the data interface itself. Expert data portals typically incorporate expert terminology, and the navigation through these portals to obtain and visualize data is often non-intuitive to novices. The challenge when designing education interfaces to these data is to simplify and streamline access while still allowing for rich learning and sustained engagement in the classroom. The discussions that follow describe what we did to tackle this challenge, and what we learned from our experiences.

ACCESSING AND VIEWING DATA SHOULD BE FAST AND EASY (PP. 48–55)

GOAL: REDUCE THE STEPS NECESSARY TO ACCESS AND DISPLAY DATA

A student-friendly interface should aim to maximize and sustain germane cognitive load by enabling students to focus on investigating and generating questions using the available data, visualizations, and analysis tools. Students' initial interactions with the interface are particularly important, as excessive extraneous cognitive load that they experience early on may be prohibitively frustrating or lessen their motivation moving forward. Data selection and display processes that involve numerous, poorly delineated steps have the potential to provide an early source of extraneous cognitive load and distract students from their goals for exploration.

We designed the Ocean Tracks interface to reduce extraneous cognitive load and invite exploration by removing initial barriers that novices typically encounter on an expert interface, and by minimizing the steps necessary to access and display data. We made data immediately available visually, automated the generation of data displays, and provided students with easy access to additional data sets and representations so they could devote more of their cognitive resources to thinking about the patterns that emerge from the data themselves.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal (also see Figure 3, above):

Elephant Seal 302: When students launch the Ocean Tracks interface, they are promptly greeted by Elephant Seal 302, whose track appears as a bright red line displayed on the Google Maps satellite view of the Pacific Ocean (see Figure 4). When they expand the Tools tab, they also find data from this track displayed on a time series graph. We intentionally gave students immediate access (effectively requiring no steps) to this data set as an entry point into the Ocean Tracks experience, to capture their attention by inviting them to interact with the map, the track, and, as they become more comfortable, the other data and tools available.

Simplified data selection menus: To enable students to explore data sets beyond Elephant Seal 302, we designed data access points to reduce the number of steps and level of jargon involved in the selection process. The Tracks and Overlays tabs offer quick and constant access to the wide range of tracking and oceanographic data available in Ocean Tracks using an expandable tab format, allowing users to add or remove data from the map without leaving the page and with the map representation in view. The available data sets are presented in structured formats to help students navigate the range of options. The Tracks tab is clearly organized by species and labeled with the year the tracks were recorded, and the Overlays tab provides a quick overview of the available data layers, and guides students through the process of selecting appropriate data based on the dates of the track they're investigating.

Automated data displays: In addition to making a variety of data easily accessible, we also designed the Ocean Tracks interface to simplify the process of visualizing these data. By automating the graph-making process, the interface allows students to devote more of their cognitive resources to finding and interpreting patterns in the data. Once students select tracking data to display, the interface automatically generates and optimizes the map and graph representations, and then allows students to adjust and customize these representations to suit their needs. For example, the map is automatically centered on the areas of the Pacific Ocean where most of the tracking data will be visible and in the center of students' field of vision. From there, students can pan, zoom in, and zoom out to more closely examine certain areas of the map. Similarly, when a student loads a track into the graph, the scale automatically adjusts to accommodate data from the entire track. However, students can also customize this display to hone in on a particular section of the track.

What We Learned

Facilitating data access may look different for new vs. experienced users. While students were immediately able to interact with and make observations about Elephant Seal 302, we saw some frustration as they moved on to investigations involving other animals and species. In situations where this elephant seal wasn't relevant, we had inadvertently introduced an extra step for experienced students returning to the interface who had to remove the elephant seal each time they logged in to continue their work. For these students, it was more helpful to provide access to a clean map on which they could begin a new investigation and to saved maps that allowed them to continue an ongoing investigation. This highlights the importance of reducing the steps necessary for students to access the data they need. Where first-time users may need an immediately visible introductory data set, the ability to save and return to visualizations as part of an ongoing analysis may support easier access for returning users.

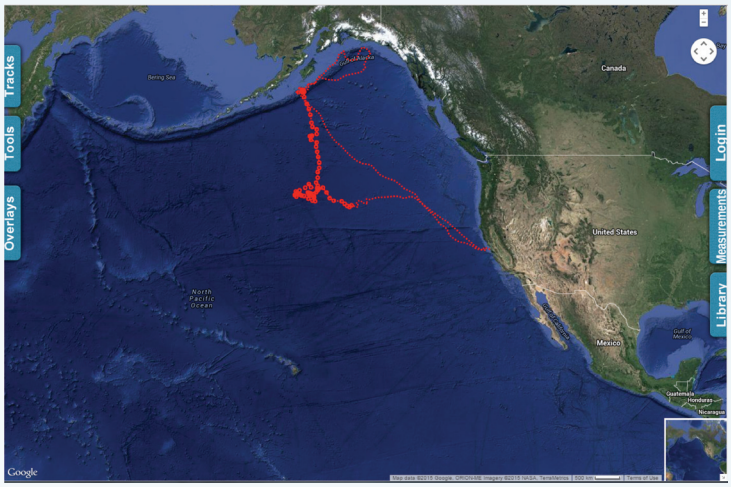


Figure 4. Users' first view of the Ocean Tracks map interface, with the track from Elephant Seal 302 in red.

Latency can introduce challenges related to accessing and displaying data. Giving students the ability to quickly select and view multiple tracks was a double-edged sword. While students were immediately able to navigate the track selection interface, fluidly adding and removing tracks from the map, there was often an initial tendency to add many tracks, all at once. In a classroom with typical computers and Internet-connection quality, this often resulted in long load times and delayed responses to their interactions in the interface. To encourage students to be more methodical in their data selection while maintaining easy access, we moved the Show/Hide All options to less prominent locations in the Tracks tab.

A tension exists between introducing scientific labeling methods and maximizing accessibility. In a professional data interface, labeling that may appear cryptic to a novice user can very efficiently communicate a lot of important information to an expert, who is familiar with the acronyms, scientific terms, and labeling norms often used to describe the data. In initial versions of the Ocean Tracks interface, we used a hybrid approach: we clearly arranged and identified each animal according to its species, but we assigned each track an identification number that distinguished that animal as an individual and communicated information about the date of the track. Students found these labels difficult to decipher, distinguish, and reference as they worked, which led us to simplify the labeling system for some species. We also found that the abbreviations for the data overlays (e.g., SST, CHL, and Bathy) weren't meaningful for many students. In the Pilot 2 version of the interface, we changed "Bathy" to "Sea floor," but we felt it was worth the time to explicitly teach students the meaning of SST (sea surface temperature) and CHL (chlorophyll).

SCIENCE QUESTIONS

The following questions guided decision-making about data, information and analytical tools to include in the Ocean Tracks interface

BIG QUESTION: What might influence the movement of pelagic marine species?

- Life-history stages: juvenile, adult
- Types of behavior: migration, breeding, feeding
- Oceanographic factors: sea surface temperature (SST), thermal layers, fronts (SST, chlorophyll a), currents, upwelling, sea surface height, convergent and divergent zones between water masses
- Bathymetry: seamounts, shallow banks, continental shelf breaks, depth
- Fishing gear: longlines, purse-seins

Why might marine species movement be affected by oceanographic factors?

- High productivity leads to congregation of prey
- Efficiency/difficulty of movement in current
- Thermal tolerance

Extension Question: How does the relative importance of these factors differ across species?

- Elephant seals
- Tunas
- Seabirds
- Sharks

Extension Question: How do factors influencing marine species movement differ between coastal and open ocean areas?

How do the nature, location, and frequency of occurrence of oceanographic features that congregate marine species vary over time?

- Short timescales: monthly, seasonal
- Long timescales: interannual

Are there apparent long-term changes in these features?

BIG QUESTION: Can we predict where marine species will congregate in the future, and target these areas for protection?

USE ORGANIZATIONAL STRUCTURES THAT QUICKLY ENGAGE AND ALSO SUPPORT DEEPER EXPLORATION (PP. 53–56)

GOAL: PROVIDE A FOCUSED SET OF DATA AND TOOLS THAT ARE ACCESSIBLE, INTERESTING, AND SUPPORT A RANGE OF LEARNING GOALS

While professionally collected data offer many opportunities for authentic scientific learning and exploration, the task of working with and making meaning of such data sets can quickly become overwhelming, especially for novice users. Knowing what data to use to answer a particular question, and selecting appropriate tools to analyze or make meaning of those data, can be formidable challenges. User interfaces can play an important role in facilitating this process, particularly for users who have very little experience with a data set or with data use in general.

One approach to reducing the cognitive load is to limit and focus the options available. The full set of TOPP data considered for use in Ocean Tracks spanned more than 10 years, and the environmental data layers span an even longer time period. While providing access to the full data set may be appropriate for advanced users asking certain questions, the novice user need only view a subset of these data to explore the "stories" the data can tell and to find meaningful patterns. In addition, while an advanced user may enlist a variety of complex analytical tools to extract and model patterns in the data that are difficult for beginners, an alternative is to provide novices with a limited set of simplified tools that are useful for investigating a range of questions relevant to classroom learning goals and likely to be of student interest.

In the early stages of the Ocean Tracks project, we identified a key set of scientific questions that could be explored with the animal tagging data that were based on the kinds of questions professionals in the field were asking. We then identified the types of data that would be needed to answer these questions, and developed a set of student-friendly analytical tools that were simplified versions of the tools used by experts to explore the questions. We then focused on constraining the overall amount of data available to that which would best allow students to investigate the questions posed.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal:

Data from a limited number of species: The full TOPP data set contains tracking data from over 23 marine species. We elected to provide students with access to data from four of these species that span a range of animal types (bird, mammal, bony

fish, cartilaginous fish) and show interesting differences and similarities in how they use the ocean environment. Each species also has different conservation concerns, providing students with opportunities to learn about a variety of issues impacting the marine environment.

Data from a limited number of years: We elected to provide students with tracking data from only a subset of years of available tracking data for each of the four species. We chose years that had multiple tracks from each species, were reasonably long in their duration, and demonstrated representative patterns in that species' movements. Also, having multiple tracks within each year would allow students to compare species movements within and between years. Limiting the amount of tracking data available was also a practical consideration, meant to prevent interface sluggishness associated with loading simultaneously.

Graphing tool: The Ocean Tracks interface provides students with a graphing tool that allows them to plot track variables (speed, depth, degree of track curviness) and environmental data (sea surface temperature and chlorophyll-a concentration) for selected track intervals. The graphing tool constrains what students are able to plot on the x-axis (time), but allows the variable on the y-axis to be user determined. Although allowing students to select the variables for both axes would increase the breadth of analytical opportunities available, we ultimately decided that we wanted to focus students on the temporal and spatial aspects of the data, which is best facilitated by directing students towards time series associated with selected track intervals.

What We Learned

The data and tools in Ocean Tracks can support exploration of a range of questions (although after gaining experience, students were ready for more data): We observed that students were generally not overwhelmed with the quantity of data available in the Ocean Tracks interface and that the constrained and simplified set of data and tools supported extended student inquiry (5–6 weeks of classroom time). In fact, the interface designed for high school users quickly generated strong interest among undergraduate faculty, which eventually led to funding of our Ocean Tracks: College Edition grant (using the same set of data and tools). However, students on multiple occasions in feedback sessions and surveys at the end of their experience with Ocean Tracks requested that more data be added to the interface. In particular, students were interested in more current data. Teachers also commented on how the fact that it was "real" data was engaging to students, suggesting that students would be excited to have new data continually adding. Though much of the rich, multidimensional data in Ocean Tracks (e.g., depth and temperature information) are not available on most real-time animal tags, we are considering ways of bringing data into the interface in more of a real-time fashion that also considers the real and finite limit to the volume of tracking data that can be delivered in a Web-based experience.

There are trade-offs between constrained activities and freedom of discovery: The desire for real-time data (described above) highlights a tension that we've encountered throughout the development of the Ocean Tracks interface. We've made an effort to constrain the amount of data and tools available for students to reduce the cognitive load imposed by too many options, but this may limit the range of opportunities available for independent explorations of the data and for students to develop skills related to selection of appropriate data sets from a wider array of choices. As we continue with development efforts, we will continue to explore this balance point and whether it might be possible to create a more progressive experience, where novice users can access a more constrained data set while additional data sets are made available as they gain proficiency.

Simplified tools can make some kinds of analyses more challenging for students: Limiting the graphing capability to a time-series display of data from a single track clearly facilitated students' ability to quickly visualize and extract information about how different variables changed over time for a particular animal. However, when students needed to determine statistics across many tracks (e.g., to compare the average speed of animals within a suspected feeding area with the average speed along a migration route), it required them to use multiple graphs to make many repeated measurements, which caused their motivation to wane. Students also often struggled to describe and interpret the oceanographic overlays without tools to extract quantitative information from these images or provide summary metrics over space and time, and they appeared to have trouble drawing conclusions. For the Pilot 2 version, we added the ability for students to plot sea surface temperature and chlorophyll-a data along the track on the graphing tool, which appeared helpful for them in generating quantitative conclusions about ocean conditions. We are currently exploring graphing tools that facilitate additional statistical analyses, as well as models for integrating more flexible graphing capabilities, through the CODAP project.

GOAL: USE VISUAL ORGANIZERS TO ORIENT USERS TO IMPORTANT FEATURES AND INFORMATION

In students' initial experiences in an interface, there is great potential for them to experience extraneous cognitive load as they familiarize themselves with the range of data, tools, and information available. While some text (e.g., clear and effective labeling) is necessary and helpful, organizers that leverage our visual system's preferences and our tendency to group information based on spatial arrangements can help to quickly orient and direct users in ways that require less cognitive resources as they begin and move through their investigations.

We structured the Ocean Tracks interface to support visual orientation and navigation by centering the display on the map visualization, clustering related data and tools, and minimizing potential distractions.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following resources and features to address this goal:

The map: As we selectively process visual information in our environment, we privilege information and detail that appear in the center of our field of vision. In Ocean Tracks, we made strategic use of this on-screen real estate by building the interface around the map display. By keeping the map front, center, and visible at all times, we not only gave students immediate and constant access to spatial representations of the data, but we also emphasized the narrative aspects of the data that are made more accessible in a map view and that can inspire questions and further exploration using the surrounding interface tools.

Tabbed windows: To help students navigate the array of data and tools available in Ocean Tracks, we grouped related interface elements and embedded them in the interface using a pull-out tab system. The proximity of related tools works with our visual system's tendency to associate items based on their physical arrangement in a display, and the tab labels serve as guideposts that direct users to the appropriate location when each of these features is needed. Students can collapse the tabbed windows when they're not in use to simplify the display and minimize visual distractions not related to the task at hand.

Minimized extraneous information: Part of effectively organizing and presenting information in an interface is considering what not to include. Though there may be temptation to add "more" on a variety of fronts (e.g., analytical tools or features, explanatory text, graphic embellishments), it is important to remember that anything not relevant to the students' task at hand has the potential to introduce extraneous cognitive load. In Ocean Tracks, we avoided any temptation to add decorative "bells and whistles" to the interface display that could inadvertently distract students. We also made careful decisions about what types and amounts of visualizations, information, and functionality to provide, including only those that were most germane to students' explorations using the Ocean Tracks data and curriculum.

Supplemental cues: Where we anticipated or saw that students needed additional support in finding or attending to important interface elements, we incorporated supplemental cues to help direct their attention. For example, in classrooms where slower Internet connections caused increased load times for some of the data, students were initially confused when it appeared that nothing was happening. We added a "loading wheel," positioned strategically at the center of the screen, to alert students that data layers were in the process of being added to the map. We also added icons linked to the library and video tutorials to explicitly draw their attention to particular interface tools and features.

What We Learned

On-Screen real estate is at a premium. One common challenge across many data analysis environments is managing the layout of various visualizations, tools, and information when there is limited screen space available, particularly on laptops that are in common use in schools. We privileged the map based on its central role in both engaging students with the data and supporting the investigations in the Ocean Tracks curriculum. However, while students were easily able to locate and return to data selection and visualization tools, the tabbed window format did present some challenges. For example, at times when students wanted to work in multiple tabs at once, they encountered issues with overlap. While the ability to arrange windows would provide more flexibility, this can also add to extraneous cognitive load as students work to figure out the optimal arrangement.

There is a tension between limiting the amount of information on screen and making information visible. Reducing the

amount of information on screen at any one time makes it easier for students to quickly and visually identify important elements of the interface. However, this involved decision making about where and how to make other information available. In Ocean Tracks, we provided a number of opportunities for students to access additional information by interacting with the visualizations or navigating to a new page (see On-Demand Supports), but these features sometimes went unnoticed. Conversely, there were instances when students missed or had a hard time finding features and information (e.g., the animation tool or summary statistics on the Tracks tab), which may have been due in part to the amount of information presented at one time.

GOAL: FOSTER INTUITIVE EXPLORATION

Many of the guidelines in *Visualizing Oceans of Data* reflect the need to reduce the extraneous cognitive load that students experience as a result of the format used to present data and information in an interface. However, to support the construction of new knowledge and skills through data exploration, students' cognitive load must also be adjusted to increase germane cognitive load. To support student learning with data, it is important for an interface to be (1) intuitive—enabling students to immediately perceive and act on opportunities to interact without explicit instruction and (2) engaging—capturing and maintaining their attention and interest.

We designed the Ocean Tracks interface to support curriculum and instruction in creating a "lean in" experience for students. By bridging to familiar tools, structures, and ways of interacting, as well as providing compelling opportunities and environments for investigation, we designed the interface not just to enable but to invite and inspire students to explore the data.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal:

Familiar tools, structures, and interactions: We used several tools and formats based on their likely familiarity to students. The map at the center of Ocean Tracks was built using the Google Maps API (Application Program Interface). Most if not all students have had some exposure to Google Maps or Google Earth environments and were able to use the zoom and pan controls quite fluidly and without instruction in user and pilot tests. The interface also features a tabbed window layout that students are likely to have encountered in other software settings such as an Internet browser or Microsoft Excel. We also developed tools that enable students to manipulate the interface in ways that are tactile in nature, mirroring actions they would take with physical objects. For example, using their mouse, students can pan the map to a different location or adjust the graph's time slider, much like they might drag a paper map across the table or slide a lever to adjust the heat in their cars.

What We Learned

What is "intuitive" may vary based on the user and task. During pilot tests, we observed students attempting to interact with the interface in different ways that were intuitive to them but may not have been intuitive to others. For example, many students tried to click on a track in the map when they wanted more information about the animal or summary statistics about the track itself. We also saw that intuitive actions varied somewhat based on the task. While students were easily able to use the time slider to narrow their date selection based on visual patterns in the tracking data, they reported that in cases where they were investigating a specific date range (e.g., August 1 to August 30), it would have been easier to enter those dates rather than adjust the display using the time slider. In the Pilot 2 version, we revised the interface to allow for these kinds of direct interactions with the track.

Leveraging familiar tools can support intuitive use but introduce limitations in other areas. The Google Map centers the Ocean Tracks interface on a ubiquitous tool that, out of the box, supports the kinds of intuitive interactions and compelling visual displays described above. While we were able to leverage the built-in familiarity and affordances of these tools, they hindered our ability to customize students' experiences in other ways that would support their work with data. For example, we were limited in the types of dynamic links we could make between the different visualizations in Ocean Tracks (see Animations, p. 24). We also felt that the map scale was hard to see but were limited in the ways we could change it. An added concern is that existing tools are often easy to use because we're familiar with them, and as existing software continues to evolve, so will our sense of what is intuitive.

An intuitive interface may still have a learning curve. Although students were quickly able to create and manipulate their own data displays very early on in their Ocean Tracks experience, they still needed guidance and support in order to use the data and tools effectively in the context of an investigation. Students often began by trying to click on various elements to orient themselves and figure out how the tools worked, but many were initially unsure about how they should be using the visualization and analysis tools to engage in inquiry using the data. This highlights the critical role of curriculum and teacher facilitation.

GOAL: PROVIDE ON-DEMAND SUPPORTS THAT ALLOW FOR INDEPENDENT, CUSTOMIZED EXPLORATIONS OF THE DATA

When novice users engage in learning using scientifically collected data, they are likely to experience significant demands on their working memory as they learn to navigate and use a new interface, create and manipulate data visualizations, identify and interpret patterns in the data, and build new knowledge around complex concepts and phenomena. While an interface designed for the novice user can reduce barriers for use as well as help focus students' attention on important features and patterns, providing a variety of supports is also an important step in helping students engage with scientifically collected data. Students bring to any learning experience a range of knowledge, skills, and preferences that influence the type and timing of the supports that will be most helpful to them. In fact, providing unnecessary supports to more expert or experienced users can introduce extraneous cognitive load and distract from activities. These guidelines and considerations suggested a design approach that included resources that: support students' inquiry in the interface; are tailored to the interface and learning activities; are flexible in terms of format; and are accessible on an as-needed basis.

We developed a range of resources and interface elements to support several aspects of student investigation in the interface, including use of the interface features and functionality; creation, interpretation, and understanding of data representations; and connection to biological and ecological concepts.

Implementation in Ocean Tracks

The Ocean Tracks map interface includes the following resources and features to address this goal:

Ocean Tracks library: The Ocean Tracks library was developed as a customized resource to accompany the Ocean Tracks interface and curriculum. We developed this resource to provide a more efficient and reliable alternative to searching the Internet—both ensuring that students' reference materials were accurate and relevant to the species, data, and concepts explored in Ocean Tracks; and conserving the cognitive resources student might otherwise devote to finding and evaluating resources on their own. The library entries feature a variety of media formats, including text, photographs, concept maps, diagrams, and audio and video recordings.

Video tutorials: In Pilot 1, where much of the guidance around how to make use of the interface features was embedded into the curriculum, we saw that students could easily become overwhelmed between interface-specific supports and the activity-related guidance. It also was more difficult to coordinate textual descriptions and static images with the dynamic interactions they were designed to support. We developed a suite of video tutorials to respond to the need for more visual illustrations of how the interface tools can be used to investigate marine animals' behavior in their environment. These videos were used by some pilot teachers at the outset of the Ocean Tracks unit and were later made available via icons on the interface tabs for convenient access on an as-needed basis during an investigation.

Track statistics: Students are also able to access additional information about each animal's movement by interacting directly with the track. This includes daily statistics about the animal's maximum depth, average speed and track curviness, sea surface temperature and chlorophyll-a concentration measurements for their location, and summary information about the overall length and duration of the track.

What We Learned

The frequency of use and participant-reported value of different supports may vary. We know that students used the library frequently based on Web analytics, classroom observations, and screen flow data. We hypothesize that perhaps students

readily used this resource because they were directed to do so by the curriculum, and/or because the navigation was similar to information typically presented on other websites. The track statistics were more variably accessed and, in some cases, we observed students using them in awkward ways (or not at all). For example, several groups of students were observed clicking on individual track points repeatedly to find the beginning and end of the track, and the overall duration, instead of accessing the track summary statistics for this information. Thinking that this may have been because the icon linking them to track summary statistics was unclear to students, we changed the icon to a tab in the pop-up window called "track summary."

Students indicated that they liked the video tutorials and found them helpful, and we observed that the video tutorials were used by teachers to introduce students to the interface. But according to Web analytics, they were not frequently accessed by the students themselves. Some students indicated that they "forgot" that the videos were available, signifying to us that they may not have been sufficiently visible to the students (see below discussion). To address this, we embedded small "help" icons linking the tutorials directly into the interface. Another option would be to embed links to the video tutorials into the curriculum where students are instructed to use a particular tool or feature (as one pilot teacher did by customizing the curriculum herself).

Students and teachers valued the content, data, and interface supports that were tailored to the interface and curriculum. Pilot data suggest that the library was a useful tool that helped students make connections between the data and animal behavior in order to develop claims, support their evidence with reasoning, and ask questions. In fact, students indicated that including even more information about the animals and their behavior could further support their inquiry. Teacher and student comments highlight the importance of connecting the library resources to curriculum, where students wanted more resources that related to topics covered in a particular learning activity and where teachers requested additional content supports around ecological concepts in their own curriculum.

Effective organization and structure of supports is important. Designed and used effectively, support resources can mitigate cognitive load by helping students focus on the germane aspects of their investigation. However, it is important to minimize the working memory resources that students must use to navigate and process the supports themselves. This can be challenging when designing a comprehensive set of resources that anticipates the range of data explorations that are possible as well as students' diverse needs. Too much information, even helpful information, can overwhelm! For example, while students found the information in the library to be extremely helpful in interpreting and making claims based on the data, some teachers and students indicated that it was challenging to find the most relevant information to their investigation among the number of available entries. (Other students had the opposite experience, and described the information in the library as being "easy to locate.") In addition, some students reported that there was too much information to process when viewing all of the video tutorials at the outset of the Ocean Tracks unit, and that shorter, more targeted videos might be less overwhelming. Following post-pilot interface revisions, students can now access shorter tool-specific videos on-demand, and we are continuing to consider effective text structures, clear entry titles and organization, and search functionality in the library.

Geo-Referenced Data Representations

> *Although research indicates that spatial thinking is a skill that can be learned, it is not systematically taught in the K-12 curriculum. Perhaps because of this, even students at the college level tend to have poor understanding of geospatial concepts.*
>
> *p. 57, Visualizing Oceans of Data*

The Ocean Tracks data are in large part geospatially distributed—they are measurements that convey the animals' positions relative to other individuals; relative to oceanographic factors, such as sea surface temperature, that vary according to latitude and currents; and relative to the sea floor, which has three dimensional features that vary over space. Thus, many of the guidelines in the section of *Visualizing Oceans of Data* about Geo-Referenced Data Representations are relevant to the Ocean Tracks interface. In this section, we haven't attempted to exhaustively go through each guideline that we applied; rather, we will highlight those guidelines about which we feel have useful learning experiences to convey that aren't already covered in other sections of this case study.

Studies indicate that students often have significant difficulty understanding maps—particularly those that depict data other than the political geographic maps they most often encounter in school. And understanding data that are three-dimensional requires spatial visualization abilities that vary from student to student, and don't necessarily correlate with the abilities typically necessary to do well in school.

In the case of Ocean Tracks, we introduced a temporal element to the data that *Visualizing Oceans of Data* didn't address. We used a number of strategies, features, and tools to attempt to address these challenges and facilitate students' engagement and understanding of the geo-spatial-temporal data that are the core of Ocean Tracks. We are only at the beginning of our endeavor to do this well, and we still have much to learn.

MAKE THE IMPORTANT INFORMATION AND PATTERNS STAND OUT (PP. 63-67)

GOAL: OPTIMIZE THE VISUAL DISPLAY TO MAKE THE IMPORTANT PATTERNS STAND OUT

From the moment a user launches an interface, several cognitive functions play a role in determining what they perceive, pay attention to, and ultimately interpret as they carry out an investigation. While both expert and novice users are influenced by the biases of the visual processing system, differences in prior knowledge and the allocation of working memory resources can lead them to experience the same interface in very different ways. Over time and across numerous interactions with data visualization and analysis tools, scientists develop sophisticated and robust schemata that enable them to easily or automatically recognize the important tools and patterns that are relevant to their goals. Novice students, on the other hand, may find themselves scanning the screen as they try to find data they're interested in, the tools and controls to visualize those data, and meaningful patterns in the representations they create. The extraneous cognitive load that results from this search process may exhaust students' working memory resources and prevent them from thinking critically about the data themselves. Without experience to guide them, their attention may be drawn to the visually noticeable, regardless of its importance or relevance to their investigation.

In Ocean Tracks, we leveraged the inherent biases of the human visual system, organized and structured information, minimized distracting and extraneous information, and provided supplemental cues to draw and focus students' attention in ways that reduce the need to search and scan and help students interpret visualizations without the benefit of the robust schemata that scientists bring.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal:

Overlay palettes: The optimal palette for any geo-referenced visualization depends on the type of data (e.g., categorical vs. continuous) and whether one is seeking to discover specific patterns or details. In Ocean Tracks, we experimented with the

color palettes available through Google Maps API that varied in hue and luminance, ultimately selecting spectral palettes for sea surface temperature and chlorophyll overlays that highlight the North Pacific Transition zone and areas of upwelling. This was despite the fact that *Visualizing Oceans of Data* has strong cautions about issues with the common use of the spectral palette (see What We Learned, below, for our explanation).

Track colors: We used color in several ways to help students attend to important aspects of the track display. By default, animal tracks are color coded by species, so students can quickly identify and associate those belonging to the same species. During Pilot 1, students could also customize individual track colors to differentiate between multiple animals of the same species or to make tracks more visible against a background data layer. (We later revised this feature to automate the process of assigning unique colors) We also used color to highlight connections between the geo-referenced track displays, the graph, and related oceanographic data overlays, where track points change color in response to a hover interaction in the graph or when a data overlay is displayed that corresponds to a date range on the track.

Access to additional detail: In an effort to simplify the display and minimize potentially distracting information, we provided students with access to additional information about the data and tools that were easily accessible but otherwise hidden from view. For example, the map includes orienting geographic labels that become more detailed as students zoom in to more closely examine a specific geographic area. In addition, simple interactions, such as hovering or clicking on visualizations, will trigger pop-up windows that provide more specific quantitative or descriptive information about the data.

What We Learned

Automating display adjustments can reduce potential distractions. The initial track color selector made it possible for students to customize their own displays in situations where data overlays made the tracks difficult to see or when they wanted to differentiate between tracks using custom colors. However, during Pilot 1, log and observation data suggested that students weren't using this tool as intended. The tool was not used very often, either because students didn't notice or understand when there might be the need to customize track colors, and those who used it often did so for reasons seemingly unrelated to the task at hand (e.g., for purely aesthetic or entertainment purposes). As a result, we automated the process by adding a Unique Track Colors option that assigns a unique color to each track displayed on the map. Pilot teachers noted this shift as an improvement.

Selecting optimal overlay palettes may require compromise. While using existing overlay visualization tools and palettes allowed us to devote resources to customizing the interface in other ways, we were somewhat constrained by the options available through Google Maps API in ways that required compromise. We originally used a green palette varying in luminance to represent chlorophyll concentrations. Initial user tests and internal review suggested that students found it difficult to match the chlorophyll palette with the legend to compare concentrations in different areas. Switching to the available spectral palette resulted in easier-to-detect transitions, but also introduced opportunities for confusion. For example, the lowest values are represented using a bright purple hue that gives them undue emphasis (especially given the large areas of ocean they cover), and that can be confused with red areas representing highest values. In addition, the blue underlying bathymetry (sea floor) layer can be seen in areas where no data are available, and was sometimes confused with blue portions of the spectral palette.

USE TOOLS TO HELP STUDENTS VISUALIZE DIFFERENT PERSPECTIVES AND SCALES (P. 68)

As noted previously and in *Visualizing Oceans of Data*, working with geo-referenced data can require sophisticated spatial visualization abilities. Simply reading a map and understanding its scale is difficult for many. The ability to work in three dimensions (e.g., visualizing the horizontal and vertical components of an animal track and its relationship to sea floor features) is variable among individuals and is based in part on prior knowledge and experience. Ocean Tracks adds a temporal element—the movement of animals through the ocean over time—and that significantly increases the potential difficulties students will encounter.

Recognizing these formidable challenges, we have employed a number of strategies to help students grapple with the spatial and temporal aspects of the data and data displays. These have included the inclusion of dynamic labeling to help orient students to location and scale, track depth, and bathymetric data; time-coordinated data displays; and the animation of animal movements.

It was beyond the scope of our Ocean Tracks grant to explore students' spatial-temporal understanding of the data in any systematic way, and so what we've learned about this thus far is largely anecdotal. Because of its central importance, this aspect of Ocean Tracks is worthy of further study.

GOAL: INCLUDE DYNAMICALLY OPTIMIZED GEOGRAPHIC LABELING, LOCUS MAP, AND SCALE TO HELP ORIENT STUDENTS IN THE MAP DISPLAY

As mentioned previously, students readily engaged with the Google Maps interface and used it immediately and often to explore the map display. However, this feature has the potential to introduce confusion with respect to the scale of the display, which is constantly changing. And since physical geographic features look very different depending on the scale at which they are viewed, students can lose track of "where" they are relative to familiar locations. We attempted to minimize students' disorientation with respect to location and scale by including a number of visual elements on the interface that changed dynamically as students interacted with the map.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal:

Map labeling coordinated with the zoom tool to help with geographic orientation. The Ocean Tracks map interface includes labels of geographic features on land areas, such as countries, states, and cities, and these labels increase in detail as the user zooms in on the map.

A locus map that shows the current map view within a larger view. There is a locus map in the bottom right of the map interface that shows the map view within a larger view. This view adjusts as the user zooms in and out.

A bar scale that dynamically adjusts with the zoom to show distance measurements. A bar scale at the lower edge of the map interface automatically adjusts the distance it represents as the zoom level changes.

What We Learned

Students' prior familiarity with maps of geographic areas can affect their ability to describe animal movement relative to geographic location: All of our pilot classes were located on the East Coast of the United States, and one of the classes included many students who were recent immigrants from Europe, who at first assumed that the U.S. West Coast was the European coast, and the Pacific was the Atlantic.

Understanding the map scale can pose significant difficulty for some students. We observed one student unable to describe the size of an area where sharks congregate called the "White Shark Café," even though she had devoted significant time to studying it as part of a senior project. We added the bar scale feature to the interface to help alleviate this problem, but the scale, available in the Google Maps API, is very small and difficult to see. We wonder if a larger/more prominent scale, and perhaps one that is movable to different areas of the map, would make it easier for students to understand the scale of features. Also, because the Pacific Ocean is vast, and areas of study may be far from familiar land features, it might be helpful to have a tool that allows students to compare ocean areas to familiar land areas such as states.

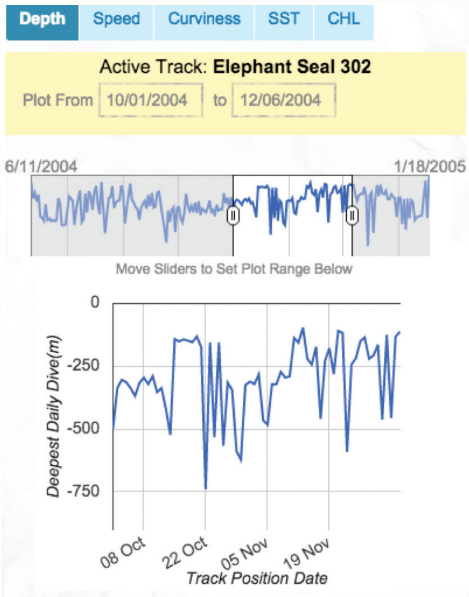


Figure 5. The deepest daily dive depth is one of the data types available in the Tools menu.

GOAL: INCLUDE DEPTH DATA AND A BATHYMETRIC MAP TO CONVEY THE THREE-DIMENSIONAL MOVEMENTS OF TAGGED ANIMALS, AND THEIR RELATIONSHIP WITH SEAFLOOR FEATURES

The track displays on the Ocean Tracks interface are two-dimensional, but the ocean's animals move in three dimensions. The diving behavior of some animals, such as the elephant seal, are associated with feeding, and depth data are recorded by their tags. To convey the vertical dimension of movement, we included data about the deepest daily dive in the interface. We also included a shaded relief map of bathymetry to encourage students to consider the relationship of animal movements to sea floor features.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following feature to address this goal:

Depth data is depicted in the graph display: In the Tools tab of the interface, students can elect to display depth data for the activated animal track, and it generates a graph of the deepest daily dive for this animal (see Figure 5).

A bathymetric map is included as one of the data overlays. A map showing sea floor depth is included in the default data display, and students can also choose to display it via the Overlay tab.

What We Learned

The depiction of depth data on a graph can be confusing to students. The depth data proved to be particularly challenging for students for a number of reasons. Students were confused by the presentation of depth data as negative values, which indicate depth below the surface. In addition, depth data aren't currently available for tuna, which led some students to incorrectly conclude that tunas don't dive below the surface. It also confused students that depth data weren't available for albatross, which only dive to shallow depths. In both instances, these findings suggest that perhaps students have limited experience interpreting graphs that go beyond typical x-y depictions of positive values, and/or have missing data. They also perhaps weren't accustomed to looking at the data critically and relating it to the expected behavior of the animal being studied.

Students had difficulty understanding the relationship of the track to the sea floor. Although the seafloor map employed variations in luminescence and shading to convey the shape of features, which is consistent with the *Visualizing Oceans of Data* guidelines, some students still confused trenches with ridges. Their interpretations were further complicated by a lack of labeling of seafloor features. Also, we included data about the vertical component of the track—the deepest daily dive—but not the corresponding depth of the ocean. Thus, the relationship wasn't clear to students. They typically assumed, for example, that if an elephant seal was diving deeper in a certain area, it must be feeding along the bottom. However, it is impossible to determine from the dive depth alone what the seal's depth was in relation to the sea floor, leading students to erroneous conclusions about where seals are feeding. For example, elephant seals often feed along the top of seamounts, which are much shallower than the surrounding sea floor.

GOAL: AUTOMATE AND VISUALLY LINK THE TIME COORDINATION OF TRACK AND OVERLAY DATA TO FACILITATE STUDENTS' UNDERSTANDING OF TEMPORAL RELATIONSHIPS

Sea surface temperature and chlorophyll-a concentrations are related in important ways to marine animal movements. For example, the North Atlantic Transition Zone (NPTZ), an important feeding area for many marine species, is reflected as a "front" with rapid transitions in temperature or concentration in these data layers. However, the location of this feature shifts seasonally. An individual animal track typically spans over multiple seasons, so it's important to understand what portion of the track corresponds in time to the location of the NPTZ. To allow students to explore this, we needed to include multiple data layers corresponding to different periods of time, and we needed to help students coordinate these data layers with the appropriate portions of the track.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following feature to address this goal:

Time-coordinated overlay data. Ocean Tracks provides overlays depicting monthly averages of sea surface temperature and chlorophyll-a concentration for all of the months associated with the tracks. To display an overlay, students select a parameter and a month. In Pilot 2, we added a feature that allows students to automatically display the appropriate overlay by clicking on a portion of the track. When an overlay is displayed, the corresponding segment of the track is highlighted in yellow on the track. We also added sea surface temperature and chlorophyll-a concentration data along the track to the time series graph in the Tools tab of the interface to allow students to obtain quantitative information about these ocean conditions for specific points or sections of the tracks.

What We Learned

Students struggled initially with selecting appropriate overlays. During Pilot 1, we constrained the overlays available for an activated track to the time frame covered by the track. This was done in an effort to help facilitate students' selection of overlays appropriate for a specific track point. Despite constraining the options, students still struggled to choose appropriate overlays, likely because the process required them to first determine the month and year of the overlay they wanted to display, and then to select this time frame from the Overlays tab on the left of the screen. During this first pilot test, it was evident that students had a natural inclination to access information about the tracks by clicking on track points. To accommodate this, we built in the ability for students to access overlays relating to a specific track point by clicking on that point. Although this feature significantly simplified the process of displaying the overlay, Web analytics from Pilot 2 indicate that students didn't use this feature very much, perhaps because it wasn't sufficiently visible to the students and teachers.

Animations

While educational animations provide promising tools for enhancing learning, the potential pitfalls are numerous….

p. 91, Visualizing Oceans of Data

Principles of multimedia design suggest that the structure of an external representation should be the same as the material it represents (Betrancourt, 2005), making animated visualizations a natural choice in communicating temporal change in ways that make time explicit. However, animations are inherently challenging from a cognitive load perspective as users must perceive and hold a fleeting source of information in their working memory. The use of animations in education has garnered much interest and been the subject of numerous studies, and while there is still much to be learned about whether and how animation can facilitate learning, it is clear that interface designers should understand the potential difficulties in order to identify appropriate contexts for their use and take steps to reduce extraneous cognitive load.

In the discussion that follows, we refer to two types of animations: (1) animations where movement represents variation in data values and (2) animations where movement is used to show transitions as users move between visualization formats and adjust visualization parameters. In Ocean Tracks, we incorporated these types of dynamic displays to support students' understanding of the temporal nature of the data as well as their ability to make connections between multiple data representations.

USE ANIMATIONS JUDICIOUSLY AND IN THE APPROPRIATE CONTEXTS (PP. 94–95)

GOAL: SUPPORT STUDENTS' UNDERSTANDING OF ANIMAL MOVEMENTS OVER TIME THROUGH THE USE OF ANIMATION

Visualizing Oceans of Data outlines the ways in which effective use of animated data visualization is still being explored. It also offers guidance around the appropriate contexts and controls that can minimize the extraneous demands that animations can place on cognitive load. In adherence with these guidelines, we were careful in our decision to include the track animation tool to support student understanding of the track as representing change over space and time.

The static animal track display in Ocean Tracks doesn't convey readily the notion of time (e.g., when the animal track "starts" and "stops") nor the relationship of the track points along its path to different seasons. It also doesn't convey the temporal relationship of different individual animals (e.g., whether they were in the same part of the ocean at the same time). Since these understandings of temporal relationships are very important to drawing conclusions about the behavior of the animal, we tried several versions of track animation tools to display the animals' movements. These included animating a single track in the Pilot 1 interface, and the ability to animate all selected tracks in a time-coordinated display in the Pilot 2 version.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following feature to address this goal:

Track animation tool: During Pilot 1, we included a feature that allowed students to see the movement of the animal along the track that was activated in the Tools menu. The animation played through the entire duration of the track, from start to end, unless it was paused, in which case the animation started over from the beginning. In preparation for Pilot 2, we enhanced the track animation tool to show the movement of all animals whose tracks are displayed on the map. To help students visualize these animals' movements relative to each other in time, the animation begins with the earliest displayed track date and runs chronologically, where tracks that are formed over the same dates will animate simultaneously. We also added the capability for students to start, pause, and stop the animation at any point in the animation.

What We Learned

Students' use of the track animation tool varied, and they used it infrequently in Pilot 2. Students used the track animation tool quite a lot during Pilot 1, and from at least one classroom observation, found it more compelling than the

measurements. In this case, the students followed the instructions diligently, taking all of the required measurements. Then, when they were asked to describe what they thought the animal was doing, they ignored the measurements and played the animation, watching it very carefully and then using it as the basis for their description. According to Web analytics, students did not use the "show animal movement" feature very often during Pilot 2. This is likely in part because they were directed to use it in the first and not in the second version of the curriculum—and they may not have needed to use this animation tool to complete the activities. Also, the more sophisticated capabilities to animate multiple tracks may have confused them. If they select tracks that represent time periods with only a small overlap, only the earliest track(s) will animate for a period of time, which can make it appear it isn't working if students are focused on other tracks.

GOAL: HIGHLIGHT RELATIONSHIPS BY DYNAMICALLY LINKING DATA DISPLAYS

The Ocean Tracks map interface enables students to visualize data using three different types of representations, each of which privileges particular aspects of the data:

- Tracks on the map—animals' geographic location (i.e., latitude and longitude) through time. Animating this visualization makes the temporal aspect explicit.
- Time series graphs—change in tag-collected behavioral or environmental measures over time.
- Overlays—color-coded map layers of environmental raster data (e.g., sea surface temperature, chlorophyll-a).

Each of these representations plays an important role in exploring where, when, and why questions related to Ocean Tracks species migrations; coordinating across them enables students to explore data from different perspectives and develop deeper understandings of patterns and relationships that emerge over the course of an investigation. However, coordinating multiple data representations is hard and places high demands on students' cognitive resources. Recognizing the difficulty that accompanies the opportunity, we used animations to provide explicit and dynamic links between data visualizations to emphasize the connections and scaffold students' coordination.

Implementation in Ocean Tracks

The Ocean Tracks interface includes the following features to address this goal:

Graph interactions mirrored in the map display: Using the Ocean Tracks graph, students can visualize and take measurements from specific sections of the track. Using the time slider or date selector, they can select a specific date range to investigate, and by hovering over a point on the graph, they can take measurements from a particular day. These interactions trigger changes in the map display, where the portion of the track that falls within the selected date range is bold, and the track point that corresponds to the hover behavior in the graph changes color.

Overlays linked to graph and track: The overlay selection process is linked to the active track displayed in the graph. Once an overlay has been selected, all portions of the track that correspond to the overlay date range are highlighted.

What We Learned

Dynamic links between displays, while helpful, may not be sufficient in helping students create and coordinate appropriate data representations. Students were successful in creating a range of customized data representations as they carried out investigations. However, screen recording and classroom observation data show instances where students were creating and attempting to coordinate inappropriate representations. For example, there was sometimes confusion about whether the data displayed in the graph were from the track of interest on the map, where a student might be describing patterns or taking measurements from a graph of a different animal or species than the one they were investigating. In Ocean Tracks, students designate an "active" track to determine which data will appear in their graph, and while labeling in the graph and dynamic highlighting in the map make this connection explicit, students sometimes overlooked this information.

The coordination of highlighted track sections with overlay time periods was also not sufficient in supporting appropriate comparisons. Some students had difficulty selecting appropriate data overlays based on the portion of the track(s) they were examining (e.g., they selected overlays from a month and year that didn't correspond with the month and year of the track segment).

5. BEYOND THE INTERFACE

What we learned about other supports needed by students and teachers to bring professional scientific data sets into the classroom

Curriculum Development

As described in the introduction, the primary focus of our first few years with Ocean Tracks was development of the interface itself, along with the associated data and analytical tools. However, our driving interest was in understanding whether our interface had the potential to allow students to think with data. Did it help them explore the same kinds of questions that scientists investigate? Did it help them make meaningful observations and encourage them to draw conclusions based on data? To answer these questions, we needed to create a curriculum that would promote sustained engagement with the interface for (as it turns out) five weeks or more during each of the two pilot tests we conducted.

Implementation in Ocean Tracks

PILOT 1. Our overall goals for the curriculum were to provide students with opportunities to investigate current and compelling questions using the Ocean Tracks data and analytical tools. We wanted them to experience using the interface as a scientist would, making observations and measurements, developing claims, and supporting them with evidence. Over the course of our pilot-testing period, we created two versions of the curriculum using what we had learned from Pilot 1 to hone our approach for Pilot 2. Our approach when developing the Pilot 1 student investigations was to develop students' analytical skills by providing lots of support initially and then gradually fading supports in later investigations (see Figure 6). The investigations were more guided to begin with, with explicit instructions on what types of data to collect, and then slowly transitioned to allow students to work more independently.

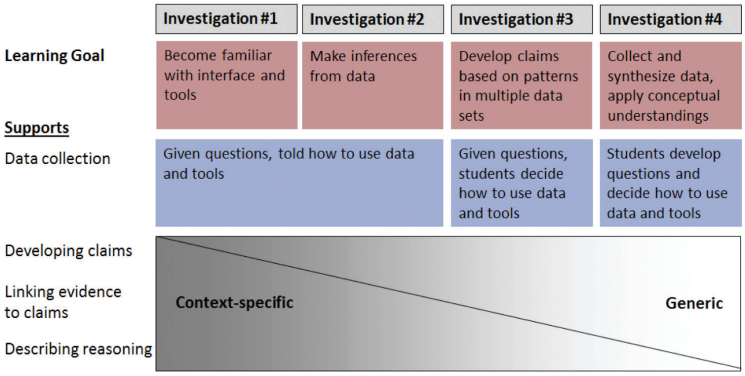


Figure 6. The Pilot 1 student investigations supported increasingly independent investigations using the Ocean Tracks data and tools.

In addition to providing instruction about this in the written modules, for Pilot 1 we integrated a student notebook into the interface. This notebook provided a place for students to organize and record their observations, claims, evidence, and reasoning (see Figure 7).

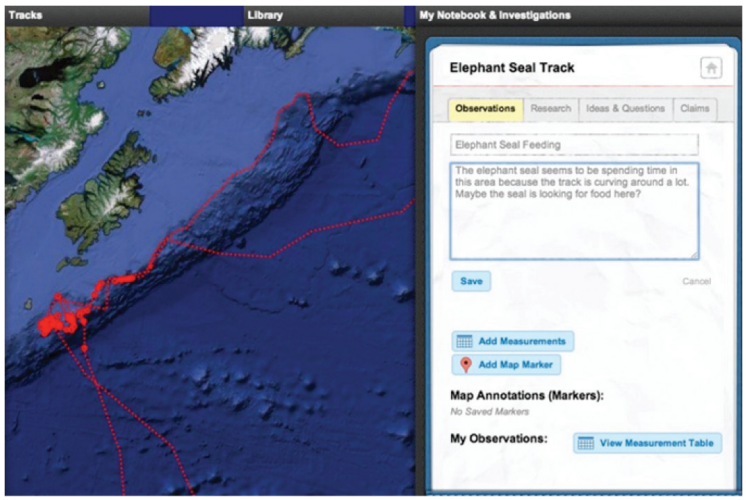


Figure 7. During Pilot 1, the interface included an integrated virtual notebook where students could record observations, claims, and evidence.

To model how scientists use animal track data to investigate animal behavior, students were initially introduced to one elephant seal track, which they explored in some depth, considering, for example, how the shape of the track reflected migration versus feeding/breeding behaviors, and how the track was influenced by oceanographic factors, such as sea surface temperature or chlorophyll-a concentration. Subsequent investigations have introduced students to more animals and species. Students build scientific inquiry skills as they progress through the modules, considering multiple variables when looking for pat-

terns and supporting claims, determining the data needed to investigate a research question, and ultimately developing their own questions to research using the Ocean Tracks data and tools. For further description of the four investigations developed for the first pilot (see Exhibit 2).

In Pilot 1, students received instructions in a printed Student Investigation Guide. This led students through a list of steps that required them to make observations and collect data while learning to use the tools of the interface. The student guide "walked" students through using the interactive notebook located in the interface for recording their responses. The guide also provided information such as how to develop a scientific explanation—defining claims, evidence, and reasoning. It provided key tips to help students better understand the data displayed on the interface.

PILOT 2. After reflecting on the success and challenges after the first use of the interface by students, we switched from using the printed Student Investigation Guides to a learning module approach. This included presentations that we created with Google Slides and shared with students, which served both to provide instructions for students and as a place for students to record their work.

TALES FROM THE CLASSROOM

Using Ocean Tracks has been an incredible opportunity for my students to work with real scientific data, designing investigations to gather data to support their claims. Ocean Tracks has made them the scientists—examining the tracks of the albatross just as a scientist might approach a similar data set. At the same time, the students were able to understand the urgency and the importance of their research. My students have increased their skills and learned many of my curriculum objectives through working with Ocean Tracks. As they learned more about the habits and characteristics of the albatross they cared about them more and were concerned when they realized the extent of impact humans create on their habitat. But what I think excites me the most is how my course this year has come full circle through this investigation. At the beginning of the year, we watched a Ted Talk by Sylvia Earle, the famous and passionate ocean explorer. In her talk she shared her wish for the oceans: "I wish you would use all means at your disposal to ignite public support for a network of global marine protected areas, 'hope spots' large enough to save and restore the ocean, the blue heart of the planet." Through the year in our class, in addition to learning concepts relating to oceanography and the biology of sea life, students have learned about many issues facing the ocean: coral bleaching, overfishing, ocean acidification, climate change, nutrient overload, etc. One of the possible solutions to help protect the oceans, which has been a recurring theme for us this year, is the formation of marine protected areas to help restore the resiliency of the ocean so that ocean life can adapt to the increasing stressors from human impact. Students have learned that conserving key habitats is necessary to improve the overall health of the ocean. This year, my students were able to actualize Sylvia Earle's wish by creating science-based recommendations for what areas of the ocean require more protection. They have been able to turn their Ocean Tracks hotspots into hope spots as they have explored the science behind creating marine protected areas.

Exhibit 2: Pilot 1 Student Investigations

INVESTIGATION QUESTIONS	STUDENTS...	SCIENTIFIC INQUIRY
Investigation #1: Elephant Seal Tracks		
What influences the migration of elephant seals? • What are the seasonal movement patterns of elephant seals? • How is the movement of elephant seals affected by oceanographic factors?	• Use background information on the biology of the elephant seals to understand migration • Learn about ways that oceanographic factors congregate elephant seal prey • Consider relationships between the movement of the elephant seal and sea temperature, currents, chlorophyll, and bathymetry	Students make both qualitative and quantitative observations, take measurements, analyze and visualize data, construct explanations from the data, develop claims, and support them with evidence.
Investigation #2: Investigating Multiple Tracks		
What creates a "biodiversity hotspot" in the ocean? • Are there regions of the ocean that attract many species and individuals? • What are the oceanographic conditions in these areas?	• Take measurements of tracks from multiple individuals to identify different behaviors • Identify habitats used by multiple species ("hot spots") • Take quantitative measurements of environmental data layers	In addition to the scientific inquiry skills from the first experience, students now also consider multiple variables when looking for patterns, and repeat measurements and observations to adequately support their claims. Students also have opportunities to recognize the limitations of the data.
Investigation #3: Investigating Changes Through Time		
What changes in marine animal habitat usage patterns and characteristics of the ocean environment do you observe between seasons and years? How can this information be used to design a conservation plan? • What are the seasonal movement patterns in marine animals, and how are these linked to changes in the ocean environment? • Are there long-term changes in movement patterns of marine animals, and are these linked to changes in the ocean environment? • What is the most effective conservation strategy for these highly mobile species?	• Take measurements of tracks from multiple months and years • Relate seasonal and yearly changes in animal behavior to characteristics of the ocean environment • Compare hotspot locations between months and years • Use what they've learned to this point to design a conservation strategy for the Ocean Tracks marine species.	Students apply and build on the scientific inquiry skills they developed in previous investigations, determining what measurements should be taken to investigate the research questions. They also consider scale when answering these questions, gathering data over multiple temporal and spatial scales.
Investigation #4: Open-Ended Inquiry		
N/A	Develop their own question to investigate by independently analyzing Ocean Tracks data	Students develop a question that can be answered with Ocean Tracks data, create a research plan to answer their question, conduct outside research on their question, obtain and analyze data from the Ocean Tracks interface, develop conclusions, and state a claim supported by evidence

Exhibit 3: Pilot 2 Student Investigations

INVESTIGATION QUESTIONS	STUDENTS...	SCIENTIFIC INQUIRY
Investigation #1: Introduction to Ocean Tracks		
• Which Ocean Tracks species is the champion of the Pacific? • Which animal traveled the greatest distance? • Which animal traveled fastest?	• investigate (working in small groups assigned tracks to determine total distance traveled and average speed traveled. • Give presentations (in their groups) and debate which animal should be crowned the winner in each category.	Students make quantitative observations, take measurements, analyze and visualize data, construct explanations from the data, develop claims, and support them with evidence.
Investigation #2: Prey Maps		
• Where are northern elephant seal prey found? • What do the data from their tags tell us about the seals' behavior? • What additional information can be gained by examining these data in the context of the environmental conditions? • How does this relate to broader principles of energy transfer in complex ecosystems?	• Take measurements from the elephant seal tracks and link them to relevant chlorophyll-a overlays to study habitat preference. • Create a food web to illustrate levels of energy transfer between organisms. • Take quantitative measurements of environmental data layers.	In addition to the scientific inquiry skills from the first experience, students now also consider multiple data sources and data types, and interpret these data in the context of broader ecological principles.
Investigation #3: Biodiversity Hotspots		
• Where are the hotspots in the Pacific Ocean? • How are species hotspots and biodiversity hotspots different?	• Use the hotspot tool to identify hotspots in the Pacific Ocean. • Determine (using the Ocean Tracks library) whether the hotspots are species hotspots or biodiversity hotspots.	Students must use background information from an external source to help interpret derivative data (from the hotspot tool).
Investigation #4: Human Impacts		
• What is the level of human impact in your hotspot? • What types of human activities are likely to impact marine animals in your hotspot?	• Use the human impacts overlay to see the extent that their hotspot (from Module 3) is affected by human activity. • Construct a plan to help mitigate human impacts on that region.	This is a fundamental exercise in modeling, where students combine data from multiple disparate sources to describe a phenomenon, and then by identifying key variables, propose a mechanism to change the modeled outcome.

Exhibit 4: Pilot 2 Student Investigations

	PILOT 1	PILOT 2	WHY THE CHANGE?	OUTCOME
Format	Printed student guide; students recorded work a in notebook embedded in the interface.	Instructions conveyed in Google Slides; students recorded work in slides.	Embedded notebook format limited teachers' ability to review student work; this function of the notebook was problematic and added undue cognitive load.	Teachers/ students preferred the Pilot 2 slide format, although learning how to use Google Slides posed some classroom challenges.
Module 1 Emphasis	DATA		Focusing on just one animal track for several weeks negatively affected student engagement.	Pilot 2 Module 1 involved many repeated measurements, which was demotivating for some students. Also, students were exposed to more animals but spent less time learning how to relate tracks to animal behavior.
	1 elephant seal track, sea surface temperature, bathymetry and chlorophyll overlays	All of the animal tracks		
	QUESTIONS			
	What are the seasonal movement patterns? How are the movements affected by oceanographic factors?	Which animal/ species travels the farthest? the fastest?		
Student Supports	More detailed, step-by-step instructions in how to use the interface features, and how to work with the data as a scientist would.	Fewer instructions; students given more freedom/ responsibility for designing steps to follow to solve challenges; video tutorials on how to use interface features available on demand	Students tended to get caught up in following steps and lost track of why they were doing the steps.	Teachers reported higher student engagement with Pilot 2 modules.

In addition to changing the way students received the instructions and recorded their responses, we also took a new approach to the curriculum itself. We scaled back the amount of instruction provided on both how to use the interface and the proper steps to take to gather the "right" measurements to support students' claims. We relied more on teacher demonstration/facilitation and video tutorials to help students learn to use the interface. By reducing some of the directions in the modules, we left students more room to think independently about the data and how to collect evidence to support their claims.

The Pilot 2 curriculum also changed the way the animal track data was introduced to the students. Instead of focusing on just one track in the first module, students were encouraged to explore all of the animal tracks and compare measurements of their speed and distance traveled. This means that they were introduced to more of the tracks but fewer of the other data types in their first experience.

In addition to developing students' scientific inquiry skills, the Pilot 2 curriculum also targeted the teaching of disciplinary core ideas related to the Next Generation Science Standards. The content learning goals were developed in consultation with the pilot teachers so that it would allow them to teach the biology content they normally cover in their courses. See Exhibit 3 for more description of the four modules developed for the second pilot.

What We Learned

Exhibit 4 briefly summarizes the key differences between our two versions of the Ocean Tracks curriculum, what compelled us to make these changes, and the outcomes of them. Because curriculum development was not the primary focus of our grant,

we did not assess the student learning that occurred during either of the pilots. However, we did probe the effectiveness of the curriculum by qualitatively reviewing student work, conducting classroom and screenflow observations, and interviewing both students and teachers.

Student engagement in both pilots was high at first, but waned as students moved through the curriculum. During both pilots, when the unit was first introduced to students, they were immediately hooked. They were interested in the animals and were voicing questions such as "Where do they go?" "How far do they go?" "Do they go alone?" But as they continued on and realized that collecting measurements, supporting their ideas with evidence, and trying to understand what the data mean is challenging, they started to lose motivation. As they moved through the unit of study, the interface began to lose its initial appeal. The repetitive nature of working with data in an authentic way required perseverance from the students. Students were challenged when they had to work without a definite "right" or "wrong" answer, to assess their work based on how well data support their claims, and to make claims based on multiple types of data and repeated measurements.

The Pilot 2 modules, with fewer text instructions, were viewed as an improvement by teachers. Based on the feedback from the pilot teachers, the Pilot 2 learning modules with less text and simpler language, were more understandable to students. The use of Google Slides provided more intuitive organization for students, allowed students to capture their customized data visualizations, and provided the added opportunity for teachers to comment on students' work, providing feedback on their progress. According to one of the pilot teachers, "It went a lot better with the shorter modules…and you could actually kind of test the students on the concepts, versus last year, it was kind of trying to get through all the information in a packet."

While the overall feedback regarding the use of the modules during Pilot 2 was favorable, we recognize that tension exists between giving too much assistance and not enough guidance. In Pilot 1, extensive guidance and instructions became more of a barrier for students, making it difficult for them to see the bigger picture. During Plot 2, with less instruction, students had to do more independent thinking to determine their methodology, since this required them to constantly be aware of what they were trying to accomplish. A consequence of this, however, was that students didn't always know the best way to approach their data collection or what kinds of evidence would best support their claim. Striking just the right balance of providing enough guidance to help students develop the necessary set of skills while still allowing them the freedom and creativity to approach the activities in their own way is something that we are still exploring and striving for.

TALES FROM THE CLASSROOM

After students had determined this "hot spot" for the albatross, they then investigated the level of human impact here using a data overlay on the Ocean Tracks site. They determined that the foraging hot spot was at a cumulative impact level assessment of medium-high impact. My students wanted to know why—what are the types of human impact in this area and how might those impacts be affecting the albatross? As a way to keep my students engaged while completing the learning modules on Ocean Tracks, I tried to break up our computer time with offline days. On these days, I tried to focus on activities that would help increase the relevancy of the data that they had been studying to help students understand the significance of their data collection. These activities explored human impacts on albatross populations. As part of their work for the fourth learning module of Ocean Tracks, my students decided they would like to create a marine protected area that would help protect the albatross from these threats by cleaning up the plastic pollution and limiting longline fishing in this region of the ocean.

Peer-to-peer interactions appeared to improve student engagement in the learning experience. We found that peer-to-peer interactions seemed to help support learning in this more open-ended approach. Students were able to confer when interpreting data or reading data visualizations. In some cases, the nature of the group work allowed students to divide and conquer, thus limiting the amount of data collection that any one individual had to complete. This allowed the majority of their time to be spent on the analysis of the data and not just the collection of measurements. The small-group work created opportunities for students to help each other overcome challenges, be responsible and accountable, and build interpersonal skills.

Completing the modules took longer than we had expected. To achieve the learning goals that we set for students, we learned it takes a lot of time to help them work with these kinds of data. Both pilots took five to six weeks of class time, and most teachers were unable to complete all of the investigations/modules in either pilot. One teacher who continued to do Ocean Tracks in subsequent years reported that implementing the modules in their complete form took up to eight weeks of dedicated class time. Some teachers suggested that they might incorporate Ocean Tracks at various points over the course of a year, rather than in a back-to-back sequence, to lessen the possibility of student burn-out. (We are following this approach as we develop curriculum modules for our Ocean Tracks: College Edition project.)

It's important to mix online activities with offline activities. Students rely heavily on the computer when working in the interface. Learning from this one modality was hard for some students and led to a loss of engagement over time. We learned that it is important to balance online time with other offline activities. Some examples include watching related videos about the Ocean Tracks species; having students present their work to each other (sometimes sharing data or creating visuals on large newsprint paper rather than on the computer); and having class discussions regarding a related event in the news that connects to the Ocean Tracks animals. Interspersing these activities into the unit helped students stay engaged with the overall Ocean Tracks experience.

TALES FROM THE CLASSROOM

My marine biology students have proposed that the largest marine protected area in the world should be expanded. The Papahānaumokuākea Marine National Monument protects Hawaii's Northwestern Islands and is 140,000 square miles of reefs, atolls, shallow waters, and deep seas. But my students don't think this is enough protection. Their reasoning? They are concerned about the health of the Laysan albatross. This champion traveler of the Pacific Ocean is facing many threats relating to plastic pollution in the ocean and are often caught as bycatch, snared in the longlines of fishing vessels. My students want to help this skilled ocean navigator by expanding the protection from where the animal breeds to also include where these animals go to feed.

Diversify the ways that students can show what they've learned. One teacher noted that she found value in diversifying the way in which students were allowed to demonstrate their learning. Examples include writing a children's story or a letter to a TOPP scientist describing the behaviors of Elephant Seal 302, creating an infographic showing the statistics for the champion Ocean Tracks species, or having an online discussion/debate about human impacts.

Include activities that help students relate to the data. Also important for maintaining student engagement was to build in opportunities throughout the unit for students to be able to make a personal connection with the data. In one example, students create a depiction of what their own track would look like if they wore a satellite tag over the course of a day. This was taken even a step further on a field trip, as students experimented with a GPS app on their iPhones, creating tracks of themselves as they explored the intertidal zone. Another way that students connected with the data was through the scientist videos that were created for Ocean Tracks. The scientists explained the importance of the tracking data and how the data are used, reinforcing the real-world relevancy of the data for students. Also, teachers taking the time to go into more depth with students about how these species are affected by human activity helps the students see why the work they are doing is important.

The greater focus on the science content standards allowed for better integration with high school biology courses. According to one pilot teacher, "We got through probably two or three chapters of the textbook by doing Ocean Tracks instead…they got exactly what I needed to get across with the science standards." Tightening up the connections to the content standards made the teachers feel more comfortable spending their class time on the Ocean Tracks modules as they were able to use it in place of their regular curriculum.

Supports for Teachers

As with the development of curriculum materials, the creation of teacher supports was not a primary focus of our initial Ocean Tracks grant. However, recognizing the critical role of teachers in facilitating students' work with authentic scientific data sets, we created basic supports and placed a high priority on gathering information about teacher needs. Most significantly, our outside evaluator placed a primary focus on gathering data from pilot and non-pilot teachers about the classroom value and usability of the Ocean Tracks interface and supporting resources, as well as additional resources needed to support integration in their classrooms. This section quotes significantly from these findings.

Implementation in Ocean Tracks

The professional development and teacher supports that we provided included virtual and in-person training sessions, a teacher's guide, and in some cases live support in the classroom during observations from the Ocean Tracks team. The professional development training sessions allowed the teachers to work one on one with the Ocean Tracks team, and also to work closely with each other. This program included demonstrations of the Ocean Tracks interface, discussions with Ocean Tracks scientists about what the data show, and a review of the learning goals and research activities in which they would be engaging their students. In addition, teachers had time to experiment with the interface while being able to ask questions of the Ocean Tracks team. Teachers also used this time to talk with each other and brainstorm lesson planning ideas. They discussed obstacles they might encounter with their students and problem solved with each other.

TALES FROM THE CLASSROOM

Students have learned about the speedy migrations of the albatross through their investigations using the Ocean Tracks interface. They have learned how fast (up to 65 km/hour) and how far (up to 500 km per day!) this animal travels. They have learned about the animals' cool adaptations through the use of the Ocean Tracks library, like their huge wingspan (up to seven feet) that aids in their dynamic soaring. This soaring technique allows them to use energy from the wind generated from repeated rising and descending to keep them in motion while barely flapping their wings. Through their observations of the Ocean Tracks maps, students saw that the albatrosses were leaving from and returning to an island in the Northwest Hawaiian Islands and hypothesized that animals were breeding and raising chicks there. Students described how the birds would leave for upwards of 25 days on foraging trips covering up to 10,000 km. They studied overlays of sea surface temperature and chlorophyll concentration and concluded that the animals were headed northwest towards Japan and Alaska to find food along the North Pacific Transition Zone. The seabirds would then return to their nests and regurgitate their food for their chicks. Using the hot spot tool in Ocean Tracks, students were able to light up areas of the ocean that had a higher track density to further pinpoint these feeding locations. These foraging areas are the locations my students want to protect.

To further support the teachers as the facilitators of these investigations with their students, a teacher's guide was created. The guide is a supplement to the student curriculum modules and is intended to provide additional helpful information for the teachers. This guide identifies learning goals and related standards, suggestions for implementation, possible points of confusion and clarification, and useful resources to help teachers as they deliver the Ocean Tracks curriculum. The guide also lists potential prompts for class discussions and ideas for possible off-line activities to support the students' work with the interface.

What We Learned

The Ocean Tracks interface shows a substantial improvement in usability and accessibility over previously available resources for teachers who want to incorporate real scientific data into their classrooms, but more supports are needed. When comparing non-pilot teachers' reflections on the GTOPP website (which provides un-scaffolded access to marine wildlife tracking data) to Ocean Tracks, evidence shows that Ocean Tracks fills significant gaps. Teachers felt the interface would be usable in their classrooms and engaging to students. Teachers did not indicate the need for technology infrastructure or IT support, and, in contrast with comments about the un-scaffolded interface, they did not focus on the need to spend time preparing the data itself for student use. Teachers did indicate the need for more content knowledge in marine science and oceanography, and described working with data as an unfamiliar skill set and approach for students, requiring significant thought and planning to implement smoothly. Teachers specifically mentioned the need for additional teacher training in the form of a tutorial video or a workshop to help them learn more about Ocean Tracks and how to effectively teach with it.

We observed a steep learning curve with the teachers who are using the interface for the first time. Initially, our pilot teachers had to put in a considerable amount of time to work with the interface and understand its capabilities, but that initial investment paid off and allowed teachers to then have a lot of success using the website. Pilot 2 involved three teachers who were a part of Pilot 1 the spring prior and two new teachers. The teachers who had participated previously reported feeling very prepared to use the interface with students. The new teachers felt a bit intimidated by the interface and less prepared, which made it more difficult for them to help their students. This confirms the importance of providing teachers new to Ocean Tracks with considerable support, including opportunities to practice using the interface themselves. Data suggest that without greater supports for teachers to learn Ocean Tracks, the platform may be limited to use by only the most motivated and data-experienced teachers (Sickler & Cherry, 2013).

Data suggests that implementation of Ocean Tracks learning resources will likely vary dramatically when put in the field. Across the board, teachers talked about adapting the Ocean Tracks materials to suit their own needs and practices. Comments included timing (spreading learning modules through a year), "picking and choosing" between modules, using the interface without the curriculum modules, reformatting modules, and creating different activities. This suggests that teacher training in how to incorporate Ocean Tracks in a variety of classroom contexts is very important.

It may be beneficial to provide opportunities for teachers to share "tips and tricks" that emerge from repeated classroom practice. For example, the pilot teachers each concluded over time that paired or small groups of students were ideal for Ocean Tracks. As the network of teachers reveals other common successes or variations that represent a good fit to a given context, documenting and sharing with new teachers may further speed their successful implementation. Non-pilot teachers also expressed an interest in having opportunities to collaborate with other teachers, both online as well as at their own school. One teacher suggested having a teacher-dedicated portion of the website for sharing resources.

Work with authentic data sets is considered by some teachers to be only suitable for "advanced" classes, and this could limit broad dissemination. Although the Ocean Tracks pilot classrooms represented a broad range of classroom contexts, including one urban class with primarily ESL students, interviews with non-pilot teachers revealed that they perceived Ocean Tracks as best suited for advanced, but not basic, biology classes. This suggests teachers may need more supports and guideposts about how to adjust the modules or teaching to ensure that working with authentic data is an experience to benefit learners of all abilities.

Process Management Supports

Throughout the development of the Ocean Tracks interface, we have sought to craft tools allowing student users to capture the work they are doing, both as a means of organizing and documenting their own thought processes, and by extension, to provide a means for their teachers to review, evaluate, and provide feedback on their work. In its most ideal form, a process management tool would be seamlessly integrated into the interface itself and would help us to achieve three overarching goals:

1. Preparation (before the experience): A process management tool would help teachers plan the experience for their students. This might include creating specific instructions, lesson plans, and outside source materials.
2. Facilitation (during the experience): A process management tool would support the students' use of the interface, and would give them a way to structure and document their thought processes as they go through the experience. At a minimum, it would allow students to readily access the instructions, questions, etc., they need to undertake the experience at hand. Such a system could promote "scientific habits of mind" by helping students to think in terms of making observations, stating hypotheses or assertions, supporting those hypotheses with data, and sharing conclusions. It could also provide the means of documenting the work itself, which might include writing in response to questions or prompts, taking screen grabs, and writing notes or annotating maps.
3. Evaluation/Feedback (after the experience): A process management tool would allow the instructor to easily review the students' work and provide feedback to them in a way that is straightforward and efficient.

Process management has proved itself to be one of the most complex elements of Ocean Tracks and is still a topic on which our team is actively working. We tested two very different approaches in the Pilot 1 and Pilot 2 test phases of Ocean Tracks; we tested yet a third approach in our CODAP classroom test in spring 2015; and we are investigating other alternative solutions as part of our ongoing Ocean Tracks: College Edition work.

Implementation in Ocean Tracks

The Student Notebook: During Pilot 1, we developed an integrated notebook tool, which could be accessed within the Ocean Tracks interface. The use of this tool required each user to have a unique username and password to ensure that they had access to their own work from session to session (typically on different laptops each time). Once they logged in, the tool itself required them to select the specific module they were going to be working on, and they were then presented with a series of tabs (Observations, Research, Ideas and Questions, and Claims) in which they could record their work.

Google Slides and Google Drive: Based on the feedback we received and issues we observed during Pilot 1 (see "What We Learned" below), we decided to take a very different approach to process management in Pilot 2. Rather than trying to integrate process management into the interface, we opted instead to use the system that was already being deployed in the classrooms where we were testing, namely Google Slides and Google Drive. During these tests, instructions and prompts were delivered in the form of Google Slides, which the students accessed in their individual Google Drive accounts. (Note that this was a system that several of the classroom teachers were already using, so the students were familiar with this approach.) Students then recorded their work directly on the slides and saved them to their Google Drives. The only embedded notebook feature that remained within the Ocean Tracks interface was an interactive Measurement Table, where users could record data into a pre-labeled table with column names corresponding to those data types available in the interface (e.g., track, start date, end date, distance, duration).

What We Learned

The utility of the embedded notebook was limited for students and teachers. During Pilot 1, the embedded notebook had mixed success. While we observed numerous students who familiarized themselves with the notebook interface and were able to use it effectively, it presented problems to others. In some cases, these were interface related; for example, users sometimes had problems knowing how to begin a new entry or how to find or edit entries they had already made. In other cases, the issues were more content related, as when users weren't sure what distinguished Observations from Research, or Ideas and Questions from Claims, entering similar information to multiple tabs and becoming frustrated that what they were being asked to do was "redundant."

We also found that in the prototype notebook interface that we tested during Pilot 1, it was cumbersome for teachers to review their students' work, and there were no mechanisms for them to provide feedback within the interface. Ultimately, we decided that creating an embedded notebook that addressed all of the issues we had encountered would require far more time and effort than we had available during this exploratory project. So, following the advice of our advisory board, we decided to instead look for options that were more "off the shelf." We made it a high priority to address the teachers' need to review student work.

There were significant advantages to moving student work outside of the interface. During Pilot 2, when the only embedded process management tool was the Measurement Table, we found that there were some significant advantages in moving the student work outside of the Ocean Tracks interface. By embedding instructions and prompts together in Google Slides, students found it easier to record and present their work, and teachers were better able to review and provide feedback. There was also a greater tendency for students to illustrate their findings using annotated screenshots of the map, which we attribute to the familiarity (to many of the students) of the graphics tools afforded by Google Slides. However, we found that the use of Google Drive presented its own challenges with file management, file naming conventions, etc. And when students and teachers did not have prior experience with Google Drive, the associated learning curve consumed classroom time.

An optimal process management solution should allow users to smoothly and seamlessly navigate among the map interface, the instructional materials they are using (whatever form they may take), and the medium in which they are capturing their work. While it may seem ideal to integrate such process management supports directly into the interface, this approach comes at two significant costs: (1) It limits flexibility to customize those supports from classroom to classroom, since the more integrated the materials become, the more they require specialized knowledge and skills to modify them; (2) because most classrooms already use some sort of classroom management system for online work, the use of a custom-built system in Ocean Tracks requires both teachers and students to learn a new system—increasing the cognitive load and potentially causing confusion with multiple usernames and passwords, file organization and management schemes, etc. At the time of this writing, we are working with our technology partners to survey the landscape of classroom management systems and process management tools to see if there might be a way of bringing together the best features of all these worlds.

6. SUCCESSFUL PARTNERSHIPS FOR INVOLVING STUDENTS WITH PROFESSIONAL SCIENTIFIC DATA

Foundational to the development of the Ocean Tracks interface and supports has been the collaborative efforts of our interdisciplinary team, which has included scientists, education specialists, teachers and technologists from across the U.S. and Canada. From day one, we've been teaching and learning from each other, and we feel this has greatly strengthened our work and its products. We've also derived great benefit from project Advisors, which expanded and deepened the expertise we were able to apply to development efforts.

The diversity of our team has been our strength, but the make-up of the team alone doesn't guarantee productive collaboration. Because we come from different "worlds," we've had to be purposeful in how we design our interactions to ensure that we are understanding each other and are fully taking advantage of the expertise that we represent. The ways in which we have shared the workload, our systems for communication, and our decision-making processes have been critical, particularly since our team makeup has evolved as we've engaged with work on multiple grants.

What strategies have we used to forge successful collaboration with an interdisciplinary team to create educational tools that involve students with scientific data? What has been the role of scientists? education specialists? teachers? technologists? This section describes what we've done, and what we've learned.

Implementation in Ocean Tracks

Our Team: From the very beginning, the Ocean Tracks team has had members representing multiple disciplines. These include:

- Classroom teaching (initially high school, now including also faculty from a community college and a four-year undergraduate institution)
- Curriculum development (our current team includes three textbook authors!)
- Education research
- Marine biology and oceanography research (we currently have 4 team members with PhDs in marine biology or oceanography, including those actively involved in scientific research)
- Software engineering
- Business/commercial development

It's worthy of note that our team is also spread out geographically, with team members working together virtually from offices in six U.S. states (Massachusetts, New Hampshire, New York, New Jersey, Ohio and California) and two Canadian provinces (Nova Scotia and British Columbia).

Our advisory board members were also carefully selected and recruited for their expertise in areas we knew would significantly enhance our work and products (see Exhibit 1, pg. 8). These included:

- Marine sciences (e.g., marine biology, physical and chemical oceanography, climate science)
- Data science (e.g., cyberinfrastructure, data collection technologies, geospatial visualization, mathematical modeling)
- Learning and teaching (e.g., cognitive science, digital curriculum, geospatial thinking, learning technologies, scientific thinking, statistical reasoning)

Our work together: We have weekly team meetings that take place in a virtual conference room using video conferencing technology. These are working meetings with agendas laid out in advance and goals for the work we plan to accomplish. Smaller working groups focus on certain major project tasks, such as curriculum module development. These groups regularly bring their work to the entire team so that all of the team's expertise can be contributed to their work products. The team also has face-to-face meetings once or twice a year at critical points, such as at project kick-off or to solicit input from project advisors.

Although we have established roles and responsibilities that are based on the expertise of team members, we work collaboratively and share work tasks across disciplinary boundaries. For example, all members of the high school team spent time observing classrooms during pilot testing, and all were involved in the pilot data analyses. The project PI/PDs meet weekly to review the work that is underway, and to develop plans for getting the work done. This includes strategizing about the best ways to utilize team members' time, taking into account both their expertise and also who might be "over-loaded" and who might be available to take responsibility for certain tasks. Although we do have project PI/PDs with leadership responsibilities, the team is not structured with a specific hierarchy or chain-of-command. We work through discussion and consensus, and all team members (including those who are paid as consultants or contractors) are treated as co-equal peer team members.

We have also been very intentional in our approach to engaging our advisors over the course of Ocean Tracks development and pilot activities. Through strategic timing and a working emphasis during our formal annual meetings as well as individual consultations around specific Ocean Tracks features, we aimed to fully leverage advisors' knowledge and perspectives in ways that could directly impact and enhance the ongoing work. We structured our first advisory board meeting around collaboratively identifying, opportunities, priorities, and challenges that informed the development of the interface and curriculum used in Pilot 1. During our second meeting, advisors helped us digest findings from Pilot 1 and develop solutions and strategies for identified needs for improvement. We also reached out to specific advisors as other opportunities and questions arose that aligned with their expertise. For example Rick Lumpkin helped to produce the monthly current map layers we ultimately incorporated into the interface, and Elliott Hazen helped to identify the most appropriate sea surface temperature and chlorophyll-a datasets to use.

What We've Learned

As our team has worked together on three projects over the past five years, we've gleaned some important lessons about how to effectively collaborate on engaging students with authentic scientific data. The lessons learned below draw heavily from a team discussion focused on how we work as a team, and from reflections written during preparation of an annual report:

The active participation of all parties—scientists, education specialists, teachers, and technologists—is essential. Each member of our team brings critical expertise to our work, and it has been important that all team members have been a part of our active, day-to-day conversations. Scientists on the team ensure that the student experiences we develop are scientifically authentic, are built around current and relevant data sets, and employ the same types of analytical tools used by scientists. They have been actively involved in writing curriculum and developing background text for the Ocean Tracks library, working closely with teachers and our other education specialists. They bring an essential understanding of the data – how the measurements were made, the collection technologies used, and how they are appropriately used and interpreted to investigate scientific questions. Teachers on our team give voice to the realities of the classroom in our team discussions, communicating practical constraints associated with implementation within a classroom context, providing a check on the expectations of the team versus students' abilities and inclinations, and contributing a rich set of ideas about how to engage a variety of students. The active teachers on our team have also elected to try out the Ocean Tracks interface, curriculum and assessments in their classrooms at times beyond our formal classroom pilots, allowing for timelier, iterative feedback on program elements. Education specialists apply current learning theory to our development efforts, keep our project research questions in high relief, and ensure that our pilots are conducted to maximize what we are able to learn for ourselves and the broader education community. Our technologists have truly been co-developers of the interface, as opposed to operating as traditional contractors who execute a set of specifications. As ideas about the interface arise during team discussions, our technologist contributes suggestions and timely feedback on what is and isn't possible within the constraints of time, budget, and available software tools. The technologists' "on demand" support to teachers and students has also been invaluable during classroom pilots, and they have been able to generate new ideas about the interface design based on their classroom observations. Our technology partner also brought expertise in business and has kept our eye on what is novel and broadly useful about our work products, and ways that Ocean Tracks might be disseminated via commercial means.

Productivity is the outcome of careful planning. Planning, and the time required to do it well is often under-appreciated. The work we have done on Ocean Tracks has been ambitious, and we've had a team of as many as 16 people working simultaneously on project tasks. Ensuring that the team's work is coordinated, supported and on schedule requires a significant investment of effort. The project PI/PDs meet every week to discuss the ongoing work, assess how the workload is distributed, and carefully plan the agenda for our weekly full-team working meeting. We maintain a project timeline and a shared team calendar that facilitates work planning and scheduling. As the nature of the work shifts, we continually reassess our staffing levels, recruiting additional help and expertise when it's needed.

Meetings should be about accomplishing work. We are a virtual team that is spread across the U.S. and Canada, working for multiple institutions. Despite these obstacles, we've been able to develop a "group think" around the Ocean Tracks work, and have been tremendously productive. We believe that a critical factor has been weekly full-team working meetings, which often are two hours in length during active periods of the project. When you calculate the collective time of our large group, this is a significant investment. Thus, we designed and execute them as working meetings, as opposed to simply opportunities to hear what others are doing. [give example of what we might focus on accomplishing] Multiple members of the team chimed in about this when we held a team discussion to help us develop this section. A quote from one of our members sums it up well:

> ***I think it's nice that these meetings are productive meetings. I've been in a lot of other weekly meetings where it seems like the team is keeping in touch, but it's just sort of a report out, and you glaze over after awhile. But I feel like we use this time really wisely to actually advance the project. Everybody gets to know what everybody else is doing and be involved, rather than just sitting and listening. I think it's a really nice feature of this team that we have these conversations and try to advance things forward together as a group.***

Create a comfortable, non-competitive conversation space. The nature of our interactions during meetings has enhanced our ability to fully utilize the expertise represented by the team. As a group, the Ocean Tracks team members tend to be more thoughtful and reflective, rather than assertive and boisterous in conversations. We learned early on that we need to allow periods of silence, or "wait time" during team discussions while people formulate thoughts, and we've learned to look for visual cues that someone has something to say, or is considering the answer to a question and about to talk. As one of the team said, "Every person on the team brings enthusiasm and passion about what they do. And we have developed a shared persona on the team where nobody has to be the smartest person in the room, nobody has to protect their domain. Everybody seems to be really willing to share their thoughts and their wisdom, and is also willing to listen to and learn from others."

Meeting facilitators have made a conscious effort to intervene when they recognize expert terminology or assumed understandings arising in our conversation that may make it difficult for some in the room to participate. This has created an environment in which it is comfortable to speak up when you are confused and request clarification. A number of our team members bring experience that crosses disciplinary boundaries—for example, with experience in both science and education or communication. This likely makes them more accustomed to and open to talking in different languages with people who come from different perspectives.

Although most of our meetings are video-conferences, periodic in-person meetings, particularly at project kick-off, have been important opportunities for us to get to know each other better. And acknowledging and honoring the context of people's lives beyond work has been important to creating a respectful and sustainable work environment.

Keep virtual meetings in the virtual space. We've all been involved in video meetings in which one screen view focuses on a group of people at a conference table and there are "floating heads" projected on a screen or voices in a phone box who are joining from elsewhere. Sometimes those joining remotely have a hard time hearing what's said at the conference table, and find it difficult to read individual expressions in the conference room. Individuals joining remotely can be forgotten and inadvertently left out of the in-person meeting except when facilitators make a point of inviting them to speak. In our case, we have people participating from many different locations, and we realized our meetings worked better if everyone met in the virtual "room" using their own computer camera. This has had a kind of leveling effect on our interactions—everyone has an equally visible space at the table, regardless of their role on the project or their physical proximity And we've learned to read each other's body language, which has been important in ensuring full participation and effective communication.

Invest time in developing a common vision. Conversations among Ocean Tracks team members began five years ago, and we were actively meeting and developing our vision for Ocean Tracks for a full year before our first grant was funded. The vision formed early on has continued to evolve and grow through our work and our team discussions about it. The fact that it is "our" vision motivates us as a team to persevere in finding ways to bring the vision to fruition. This has been important as we've navigated a difficult funding environment and have had to forge ahead despite a number of disappointing rejections. It also has been important that ours is a broad vision of research questions we would like to explore and ways that Ocean Tracks can impact a variety of audiences - one that extends beyond the boundaries of any particular funding program.

It's important to have adequate resources to support and sustain the team. Despite our team's dedication to our vision, the practicalities of having to make a living in an unpredictable funding environment have taken their toll. Even when financial support for salaries is awarded, the trend toward funding smaller, shorter grants decreases the period in which team members' jobs are secure. We've lost valued core team members' to other opportunities along the way because we couldn't guarantee they would be supported. One strategy we've employed to maintain continuity and preserve valuable project experience is to offer departing staff ways of being involved for smaller amounts of time when they are available. This not only allows us to bring their experience to bear on project work, but also facilitates the transfer of knowledge to new team members. However, fully developing and researching complex programs requires dedicated staff who are able to focus on their work for sustained periods of time, and for us this has been a significant challenge.

A well-functioning interdisciplinary team yields rich professional development learning opportunities for team members. When writing about professional development opportunities for one of our annual reports to NSF, we realized that we have all grown professionally from our interactions, gaining new understandings from each other and from the work. The following are reflections of team members regarding what they have learned from working across disciplinary boundaries:

SCIENTISTS: The scientists on the project team said that it has been revealing to look at the data they work with every day through the eyes of a novice, and they are gaining a better understanding of how to support student learning of the process and nature of science. They are learning what it takes to foster and observe the inquiry process as a student progresses from observations to carrying out research and articulating ideas to making and supporting claims They've also learned a great deal about the science of education: the questions that need to be asked to understand the effectiveness of a learning tool, and the methods used to answer those questions. Their firsthand experience in the classroom during pilot testing made them more aware of the constraints present in the classroom for teachers and students from a range of backgrounds. A team member who is a recent PhD said she has gained a greater understanding of the broader context of scientific work in society, and about how to communicate that work to non-scientists. And her work with advisors in different scientific disciplines through this project has helped her as a scientific researcher by making her aware of new datasets and alternative ways of conducting research and viewing data. Our Stanford collaborating scientist said that one of the most valuable lessons from Ocean Tracks has come from the simple process of working with the Ocean Tracks team and the way that it's been led and coordinated. "This experience will serve as a model for other team initiatives in which I participate, now and down the road."

EDUCATION SPECIALISTS: The education specialists on the team have learned more about science from the scientists. In addition to learning marine biology, they've learned about the scientific habits of mind that are foundational to ecological research. They have also gained a greater appreciation of the depth of scientific thinking that scientists engage in, and the realities and complexities of presenting and working with scientific data. This has given them new insights about how to develop program elements that accurately represent the science, and how to assess students' development of scientific habits of mind. From the technologists, they've gained valuable experience with interface development, and a better understanding of the process of building Web-based data visualization tools. Although the education experts on the team bring a range of prior experience with technology development to the effort, the project work has yielded invaluable insights for all about the intersection of what's desirable and what's possible, and how to work within that intersection to build cutting-edge tools. The current and former teachers on our team have also helped align our thinking with what's possible—grounding our ideas in the realities of the classroom during each and every team conversation.

TEACHERS: Our lead teacher divides her time between Ocean Tracks project work as an EDC employee and teaching in a high school classroom. She's been deeply involved since well before the project was funded, and her voice has a significant impact on how the project work has developed. Regarding what she has learned from the Ocean Tracks project work, she says: "It has been eye opening to learn more about the field of education research and base decisions on what the research tells us instead of something instinctual. I have really enjoyed the opportunity to think about what would be best for students and make deliberate choices based on sound evidence." She also said that the project has presented an amazing opportunity to work closely with scientists and to see scientific practices in action, which has given her a better sense of how to convey those habits to students. Regarding the collaboration, she said, "This is the first time I have worked with such a diverse group with different types of expertise. Being involved on this project has given me a deeper respect for the collaboration process." She described a growing understanding that the work done by the group is greater than the work done by any one individual.

TECHNOLOGISTS: The technology developers on our team say it has been "great to be exposed to 'domain' experts on the education side" to help ground designs in education research. Most commonly these days, designs are done in feedback loops direct to the consumers, but sometimes both designers and consumers have to painfully relearn things to do or avoid that domain experts would already know." Our interface developer highlighted the insights gained from being able to directly observe classroom use, regarding the demands on teachers when in the classroom, the attention span of students, and other real-world aspects of designing that are easy to miss. The benefits of working directly with data producers and scientists on this project were also mentioned by the technologist, because this helps to ensure that data is displayed properly and not misrepresented.

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