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Education and Public Engagement in OOI

Lessons Learned from the Field

By Janice McDonnell, Annette deCharon, C. Sage Lichtenwalner, Kristin Hunter-Thomson, Catherine Halversen, Oscar Schofield, Scott Glenn, Carrie Ferraro, Carla Lauter, and James Hewlett

> "To build the most user-friendly way for professors and researchers to access OOI data for undergraduate teaching, EPE created a suite of effective tools through an iterative development cycle."

ABSTRACT. The Ocean Observing Initiative (OOI) was designed to advance understanding of complex oceanographic processes by acquiring large quantities of data at six key locations in the world ocean. The OOI Education and Public Engagement (EPE) Implementing Organization has built an educational cyberinfrastructure and developed interactive tools targeted for undergraduate-level learners that enable easy access to OOI data, images, and video. To develop the suite of OOI education tools, EPE used an iterative design process, including needs assessment, tool prototyping, and usability testing in undergraduate classrooms. Data visualization and concept mapping tools were envisioned as a way to help undergraduates link concepts students see in oceanography textbooks to real-world phenomena. A Data Investigation Builder (DIB) was constructed to assist professors in designing data activities. During the usability testing, professors provided valuable feedback that allowed EPE to improve the tools. Based on the lessons learned from EPE, in 2016 we developed a new prototype set of Data Explorations that were more modular and easier to integrate into an undergraduate lecture or problem set. This paper reviews how the EPE toolset was developed, including establishment of requirements for the tools and incorporation of lessons learned from the user needs assessment and the results of usability testing of prototype tools.

INTRODUCTION

A growing number of geoscience research programs collect high volumes of data using advanced technologies, especially in oceanography. One such program is the National Science Foundation (NSF) Ocean Observatories Initiative (OOI), which has constructed observational and computational infrastructure to provide sustained ocean measurements for the study of climate variability, ocean circulation, ecosystem dynamics, air-sea exchange, seafloor processes, and plate-scale geodynamics for the coming decades. The OOI is already advancing our ability to understand the natural world by acquiring large quantities of data to address complex oceanographic processes at six locations of interest in the world ocean.

Expanded access to online data provides geoscience professors with myriad opportunities to engage undergraduate learners through the use of real-world data sets, models, and simulations of oceanographic processes. By directly manipulating data, learners are challenged to construct meaning and develop a deeper understanding of a topic or phenomenon. This type of learning also encourages student inquiry and helps develop practical science skills (Hays et al., 2000; Adams and Matsumoto, 2009). Working with real data helps students develop interest in, motivation for, and identity with respect to science (National Science Board, 2007). Moreover, analyzing data and identifying patterns have become core skills in the workplace and for civic engagement in the twenty-first century (Oceans of Data Institute, 2015).

Despite the benefits and opportunities of having students work with real data, undergraduate teaching is often not data intensive (Krumhansel et al., 2013). Limited experience and exposure to different data types and sources can cause students to struggle in their courses, and they may purposefully avoid the use and evaluation of data in their everyday lives. Cognitive studies reveal that students who are not regularly exposed to data manipulation often fail to see patterns emerging across scientific experiments, frequently ignoring anomalous data or distorting them to match their personal beliefs (Chinn and Brewer, 1998). Studies also indicate that students need to learn more about the types of conclusions that scientists can draw from observations,

FACING PAGE. From left to right: Cheryl Greengrove (University of Washington Tacoma), Deborah Kelley (University of Washington Seattle), Alan Trujillo (Palomar College), and Rus Higley (Highline College) explore teaching with data at the Rutgers University Inn and Conference Center, New Brunswick, NJ.

what kinds of evidence are needed to support scientific ideas, and how that evidence can be gathered and interpreted (Sampson and Clark, 2008).

To support data literacy and enhance critical thinking skills, undergraduates need to transition from working with small, typically self-collected data sets to large, professionally collected data sets (Kastens, 2011) such as those provided by the OOI. Student-collected data can spur discussion of "data ownership" (i.e., provenance) and how data provide evidence for claims, interpretations, and conclusions (Hug and McNeill, 2008). However, the transition from using data they collected to using professionally collected data can be very challenging for students. They need to shift from using familiar to unfamiliar analysis tools, from hands-on experiences to gaining context from metadata, and from simple to complex lines of reasoning (Kastens, 2011). Supporting students while they transition to using professionally collected data can be challenging for professors too, as there is often a lack of adequate tools to help students in the classroom easily digest and manipulate large data sets.

With these challenges in mind, the OOI Education and Public Engagement (EPE) Implementing Organization worked to build an educational cyberinfrastructure and develop interactive tools to enable easy access to OOI data, images, and video in formal learning environments. Toward this end, we explored methodologies for effectively integrating data into learning strategies and creating data visualization tools to teach twenty-first century science skills and practices in undergraduate classrooms. To build the most user-friendly way for professors and researchers to access OOI data for undergraduate teaching, EPE created a suite of effective tools through an iterative development cycle. This paper reviews how the EPE toolset was developed, including how the requirements for the tools were established, and how we folded in lessons learned from the user needs assessment and results from the usability testing of the prototype tools. Our experiences will help future developers interested in learning about effective processes for building their own educational tools and content.

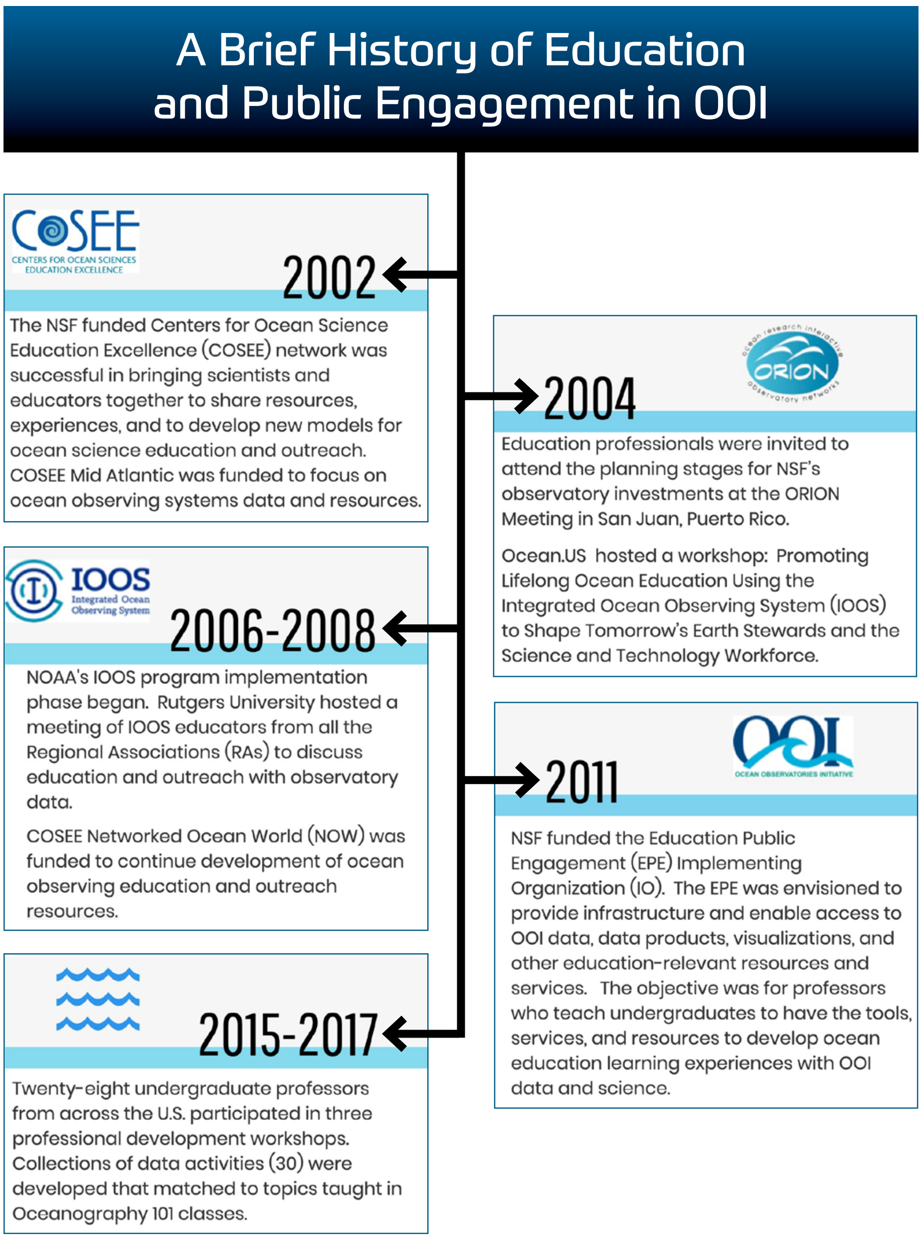


FIGURE 1. The progression of thinking about using data in teaching and learning.

HISTORY OF EDUCATION AND PUBLIC ENGAGEMENT IN OOI

Education and public awareness was a crucial component of the early Ocean Research Interactive Observation Networks (ORION) program (Matsumoto et al., 2006) that eventually evolved into the OOI program.

From 2002 to 2010, there was a national focus on ocean science education, especially through the NSF-funded Centers for Ocean Science Education Excellence (COSEE), NOAA's Integrated Ocean Observing System (IOOS; Simoniello et al., 2010; Pfirman et al., 2011), and the EPE Implementing Organization for OOI (Figure 1).

Early OOI strategic planning called for a central coordination office, as well as collaboration with a national network of observatory educators who would welcome sustained partnerships with scientists and engineers (Matsumoto et al., 2006). Educators and scientists articulated the need for a data management and information translation facility that would be tasked with transforming OOI research results, technology innovations, and data into ready-to-use forms for a variety of education and outreach audiences.

In 2011, NSF funded the EPE Implementing Organization (IO) for the OOI. The overarching objective was to develop tools and approaches that leverage the unique science and engineering capacities of OOI. EPE IO's charge was to facilitate and support education and outreach; however, the team was not supported to create educational projects or products per se. Based on NSF guidance, the primary focus of the OOI project was on developing infrastructural tools to support undergraduate education. The EPE team was led by Rutgers University and included the University of Maine, Raytheon Web Solutions, and education liaisons from the other previously awarded IOs: The University of Washington, Scripps Institution of Oceanography, and Oregon State University.

THE PROCESS: BUILDING EPE TOOLS FOR UNDERGRADUATE STUDENT LEARNING

EPE used an iterative design process to support the use of OOI data in undergraduate teaching (Figure 2). The EPE team conducted user needs assessments and usability tests, and developed a number of prototype tools with professors who teach undergraduates.

Needs assessments consisted of phone interviews in 2011 and 2012 with professors who were teaching undergraduates as well as a national survey in 2012 (n = 133; response rate 14%). We focused on understanding undergraduate teaching practices employed at the time and collecting example summaries of how data were used in undergraduate classrooms. These data were synthesized into recommendations to aid OOI software developers in designing tools that would enable undergraduates to interpret and analyze oceanographic data. Overall, assessment results showed professors were interested in using data sets to connect important themes and concepts in introductory oceanography courses. They wanted simple, clearly defined variables that are easily grasped by students. They preferred temporally based and easily manipulated data and visualization tools that allowed for easy downloading of outputs. Finally, they requested metadata to bring the context of data into student-centered activities while supporting conceptual understanding.

These professors also recommended that EPE develop tools for creating basic statistics (e.g., calculation of mean, standard deviation, standard error, correlation coefficient, regression line), interpolating data, and helping students visualize time-series data sets (McDonnell et al., 2015). The professors also supported the development of a specialized tool that would allow them to create lessons using OOI data, rate

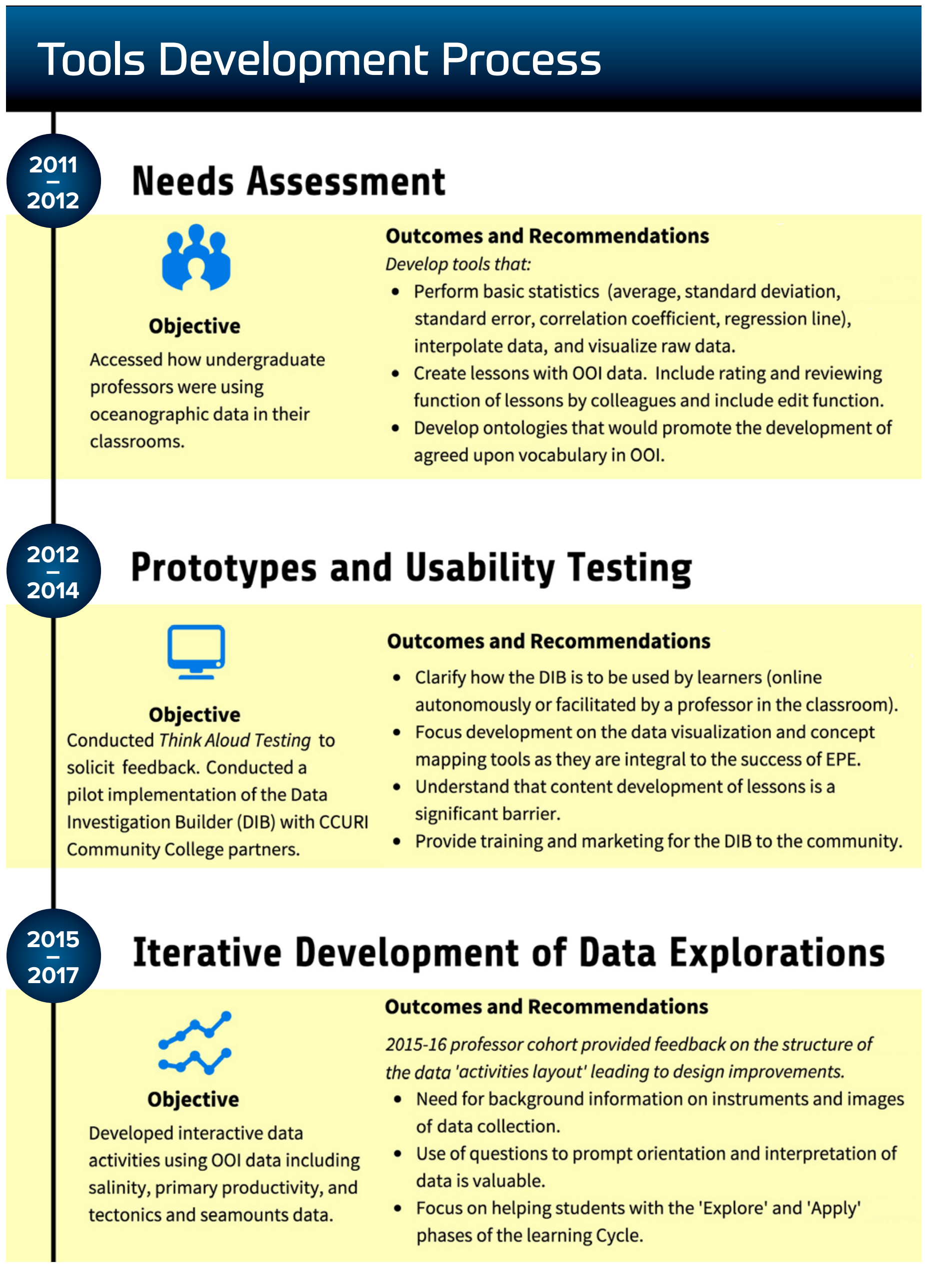


FIGURE 2. The OOI Education and Public Engagement (EPE) used a development process that included needs assessment of the professors, prototyping of data activities, and testing with undergraduates.

or review colleagues' lessons, and copy and edit lessons created by others. They suggested that EPE continue to develop and refine the Concept Mapper, developed earlier by COSEE Ocean Systems (deCharon et al., 2013). The Concept Mapper was highly regarded by the professors, who recognized its high potential for teaching oceanographic concepts. They also expressed the need for help in deciphering the extensive and jargon-heavy vocabulary of the OOI program. This request spurred development of the Vocabulary Navigator, which uses backend ontologies (deCharon et al., 2015) to display and describe connections among various components of the OOI using a concept-map format.

During 2012–2014, EPE developed requirements for its prototype tools and conducted usability testing on early prototypes. "Think Aloud" testing was used to solicit feedback from undergraduate professors at universities and community colleges. Think Aloud is a method of user testing that involves asking users to think out loud as they perform a task. The protocol included collecting information on the backgrounds of the users/testers, and asking them to review time-series visualizations, "glider" tools, and the preliminary Vocabulary Navigator. EPE also conducted a demonstration of pilot EPE tools in collaboration with the NSF-funded Community College Undergraduate Research Initiative (CCURI) network.

EPE OCEAN EDUCATION PORTAL

The primary goal of the EPE effort was to develop an online Ocean Education Portal (http://education.oceanobservatories.org) to support the creation and sharing of educational resources by undergraduate faculty. The EPE portal includes a suite of tools (Table 1) that enable faculty to create custom activities online for group or individual projects that can be used either during lectures or as homework assignments. The site also includes a variety of resources to facilitate using OOI data to teach oceanography concepts.

EPE tools were designed to help students understand and visualize how ocean data and research findings are tied to key oceanography concepts. For example, the Data Investigation Builder (DIB) is designed for learners to collect and interpret their own data and/or explore research data sets to answer questions, as described by Manduca and Mogk (2002). The DIB tool assists professors in drafting student learning objectives, identifying and visualizing OOI data sets and, most importantly, creating research challenges for undergraduates to pursue. Thus, the Education Portal was designed to help students explore scientific practices (e.g., developing a conceptual model or diagram), analyze OOI data sets, construct written explanations of phenomena observed in the data, and develop new questions based on OOI data.

IMPLEMENTING EPE TOOLS: HOW CAN THE TOOLS BE USED IN UNDERGRADUATE TEACHING?

The collection of tools developed by EPE effectively integrates OOI data into undergraduate teaching, as demonstrated by results of our pilot tests (Hunter-Thomson et al., 2017). However, there is still much work to be done to facilitate the use of OOI data in education. Pilot testers stated that EPE data visualization tools provided their students with examples of how oceanographic data are collected, graphed, and analyzed. The tools also allow students to see how data can be graphed and visualized for better analysis.

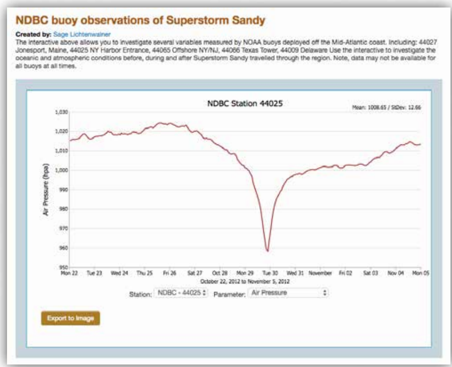
During the EPE development phase, a collection of five lessons were created in the Education Portal, entitled Ocean-Atmosphere Interactions During Storms, Salinity Matters, Seasonality in the Ocean, Is Overfishing Creating a Population Bottleneck?, and Ocean Acidification. These prototype lessons employed other data sets from NOAA as placeholders for OOI data, which were not yet available. EPE conducted formative evaluation, surveying both the professors (n = 8) and undergraduates participating in the pilot. Professors reported that these types of lessons broadened students' views from local to more regional/global perspectives. This observation was common among the CCURI community college faculty whose students had collected data locally before learning about the OOI program.

Finally, undergraduate survey results demonstrate that they need more guidance and support to learn how to interpret graphs. Students found the graphs difficult to read and interpret (e.g., the axes were sometimes unclear; more captions, key terms, visualizations, videos, and maps were needed to understand data sources; photos of instruments were requested; McDonnell et al., 2015). Some key outcomes include:

- **Data visualization tools are most critical to successfully integrating OOI into undergraduate classrooms.** Professors and their students agreed that there is great value to the types of tools developed by EPE; however, they need additional effort to increase their reliability and usability. There is broad agreement that bringing traditional textbook discussions of oceanographic concepts alive with OOI data would be of great value to students. Thus, more research and evaluation should be conducted to ascertain whether or how data interactions impact student learning and their likelihood of pursuing scientific careers.
- **Lack of model content or OOI-specific data visualization tools was a significant barrier to the success of the EPE.** The OOI construction funds for EPE were limited to tool development and could not be applied to classroom lesson development. However, supplemental NSF funding has supported the successful development of the classroom exemplars used in our CCURI pilot demonstration. Although the simultaneous development of the OOI Cyberinfrastructure/Data Portal and the EPE tools initially complicated the use of OOI data streams to test the tools and demonstrate their utility,

TABLE 1. A description of EPE tools.

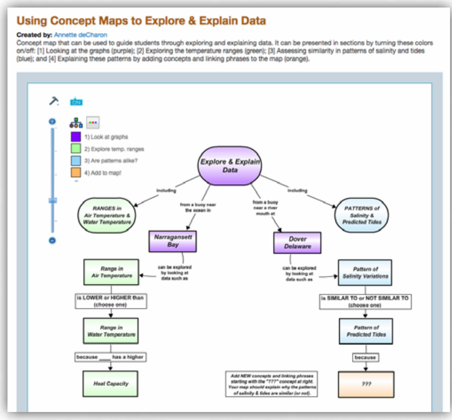
Educational Data Visualization Tools



Description. Provide simple interfaces to interact with OOI datasets. A collection of five interactive visualization tools was designed to be intuitive and adaptable to professors' teaching goals.

Key Features. One example is the "Simple Time Series" tool, which is used to select instruments and date ranges. This allows students to explore changes in environmental conditions over time (e.g., hurricanes, seasons).

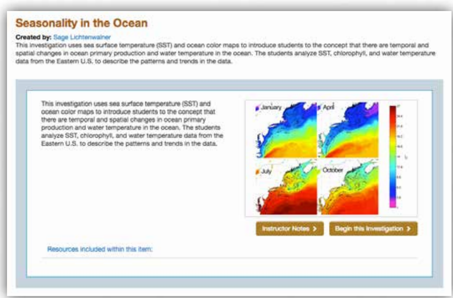
Concept Mapper



Description. Allows users to build connected diagrams of their knowledge, using shapes to represent concepts and arrows to describe the relationships between them.

Key Features. Concept maps are widely used in education to aid or evaluate students' contextual understanding of topics.

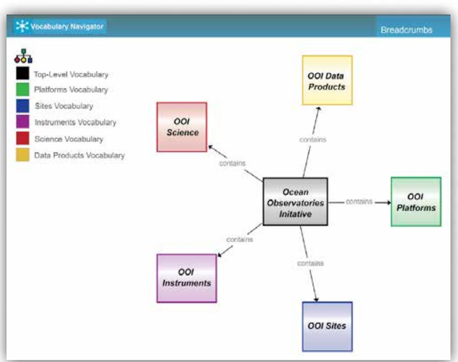
Data Investigation Builder (DIB)



Description. Resources—including OOI data visualizations, images, videos, and concept maps—can be assembled into learning modules. These lessons can also be shared with colleagues.

Key Features. Well-defined steps help educators develop lessons using OOI data. The tool promotes effective education practices by supporting students' use of data-based evidence to answer prompting questions.

Vocabulary Navigator



Description. Provides an intuitive and visual way to explore OOI's infrastructure. Its five interlinked vocabularies include terms and images from high-level science themes to specific data products.

Key Features. Based on organizational structures used in information and computer sciences, these vocabularies were designed to meet users' needs by placing information into relevant context, while promoting self-directed discovery.

it was possible to conduct some limited testing with National Data Buoy Center data. Experience, user feedback, and supplemental support have all contributed to the capability for integrating OOI data into the visualization tools.

- **Continue to develop EPE tools to support inquiry-based learning.** CCURI professors felt the DIB could be an asset for engaging in active learning and teaching. They recommended that EPE provide support for professors to create more data activities and resources, including pedagogical support for both online and face-to-face implementations. They suggested that EPE focus development on the data visualization and concept mapping tools, as they felt those tools had the most potential. Finally, they recommended EPE provide training and marketing of its tools to the community.
- **Additional professional development support for professors using the tools is needed.** EPE tools should be iterated and refined based on the types of instruction being used by undergraduate professors. For example, instructions to students will differ based on whether they are being used online autonomously or facilitated by a professor as part of classroom lectures. Lessons should be progressive and scaffolded to help students get the experience they need with data while also helping to build their confidence and skills. Scaffolding refers to a variety of instructional techniques used to move students progressively toward stronger understanding and, ultimately, greater independence in the learning process.

BEYOND EPE: DATA EXPLORATIONS PROJECT

Based on lessons learned from EPE, we developed a new prototype set of Data Explorations in 2016 (http://explorations.visualocean.net). These activities are more modular and thus easier to integrate into an undergraduate lecture or problem set. Through hands-on workshops, professors from diverse institutions—including community colleges, primarily undergraduate institutions, and minority-serving institutions—became engaged in the Data Explorations project. Overall, 28 professors participated in three OOI workshops focused on biological productivity (May 2016), properties of seawater (May 2017), and tectonics and seamounts (June 2017). Participants developed implementation plans for subsequent academic years based on the knowledge levels of their students and their course setups (e.g., face-to-face, hybrid).

Each event focused on developing effective teaching practices for using OOI data assets and customized data visualization tools. To build a community of practice among participating professors, we focused on developing content exemplars that use OOI data. Another workshop objective was to provide pedagogical guidance to professors who often do not have much opportunity to learn about effective teaching practices.

Data Explorations employed the Learning Cycle model developed by the Lawrence Hall of Science at the University of California, Berkeley, where instruction is organized to be consistent with what is known about how people learn (see Box 1). The student-centered explorations developed in this workshop were designed to connect new content to students' prior knowledge, elicit questions and explanations, provide opportunities for exploration and discussion of ideas with peers, and apply students' understanding to new situations (Lawson, 2002; Bybee et al., 2006; Brown and Abell, 2007).

To help facilitate integration of OOI data into undergraduate teaching, we identified connections between themes in

Box 1. The Learning Cycle Explained

INVITATION - Initiates the learning task and sets the context. It sparks interest, and spurs learners to recall and retrieve past connections that may be relevant to present learning experiences.

EXPLORATION - Involves exploration of real phenomena driven mainly by learners' interest and questions, followed by discussion about discoveries, results, ideas, and questions. Provides a common base of experiences for learners to develop new concepts and skills.

CONCEPT INVENTION - After interest and attention is focused, learners actively process the experience, review evidence and data gathered through exploration, and try to make sense of it.

APPLICATION - Armed with new ideas, learners apply new knowledge and skills to solving a problem or meeting a challenge, transferring their new knowledge to unfamiliar contexts in the world.

REFLECTION - After trying out new ideas in different settings, learners reflect on how their original notions have been or need to be modified. It invites them to monitor and regulate their own evolving understanding, and generate new questions.

oceanography textbooks commonly used in lower division classes (e.g., "101 level") and the OOI science themes. To enable easy adoption in community college and university 101-level oceanography courses, we purposely linked our data explorations to one of the most used textbooks in the United States, *The Essentials of Oceanography* (Trujillo and Thurman, 2016). A complete cross reference between this textbook's themes and OOI data can be found on the Data Explorations website.

ANATOMY OF A DATA EXPLORATION

Data Explorations are designed as in-class, group explorations and take 15–20 minutes to complete. One such example data activity is highlighted in Figure 3. The learning objective for each Exploration is closely tied to the Learning Cycle, with different data activities designed to be used at specific Learning Cycle phases. Thus, the learning objective and the questions students will address vary across each Exploration.

The Explorations each include a description of the student objective and data tips for the student to begin interacting with data. The activity also includes questions to prompt interpretation and analysis, facilitating each student's ability to digest and make sense of the data. Annotated background images and resources provide context. In addition, professors are encouraged to use the EPE concept-mapping tool to assess prior knowledge and reflect on knowledge gained.

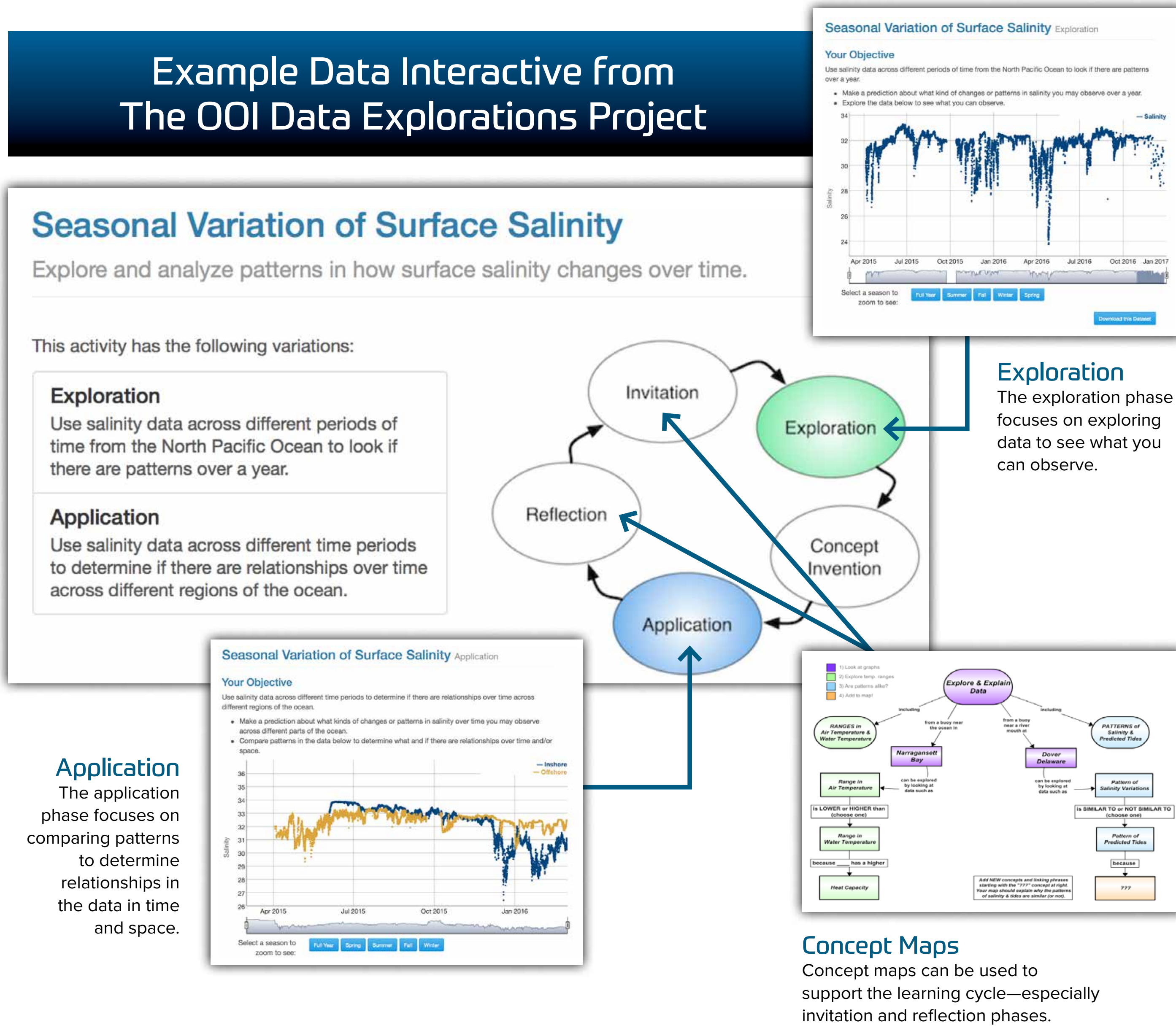


FIGURE 3. An example of one of the data activities, Seasonal Variation of Surface Salinity, from the 30 developed as part of the Data Explorations project. The data activities were largely devoted to the "Exploration" and "Application" phases of the Learning Cycle and associated question prompts. In "Exploration," the learner focuses on observations that can be made from the data. In "Application," the learner focuses on comparing spatial and temporal patterns and relationships in the data. The Concept Mapper tool was frequently used to support learning, especially during the "Invitation" and "Reflection" phases.

Professors can use Data Explorations activities to augment concepts already included in their courses. For example, if they teach about seasonal variation of sea surface salinity, they can use data activities tied to relevant OOI data sets and interactive visualizations. Given that each Data Explorations activity includes multiple options, professors can tailor them to support the learning objectives and the abilities of their students.

LOOKING FORWARD AND NEXT STEPS

We hope the community of professors using OOI data in their classrooms will continue to expand over the coming years. As we further develop content, in-person and online courses, and tutorials, we hope that leaders will emerge who are excited about engaging students in OOI data and science. We invite new partners to participate and will continue to add content to the Data Explorations website as funding allows. Finally, we will work with educational researchers and practitioners to refine our Data Explorations model, building a critical mass of exemplars and sharing effective practices in the educational literature. Our EPE experience shows that the oceanographic community needs to continue improving its data tools to support educational needs, thereby reducing barriers to accessing and understanding science content. The community needs to be able to build/update tools and content (lessons) as OOI evolves. We recommend a continued focus on developing new data activities and providing professional development to continue to expand a user base for OOI education.

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