Ocean Sciences and the Sensor Revolution: Implications for our educational system and workforce

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A strategic goal of the COSEE network is to *increase and diversify the ocean workforce*. Many changes are taking place in the ocean workforce because of changes in technology. For example, progress in ocean research increasingly relies on the convergence of traditional marine disciplines and technology. Comprehensive large-scale studies in areas such as marine fisheries and El Niño have required multidisciplinary approaches with technology playing a key role. Recent trends in technology in support of science include the increased use of 1) remote sensing, 2) computer processing power, 3) microelectronics, and 4) biotechnology—all of which are widely used in industry. However, this multidisciplinary, technology-based approach is not always reflected in our educational programs [2]. Therefore, students who specialize in any one subject to the exclusion of others, or who do not have some level of technical knowledge and skills, may have difficulty finding a job upon graduation. The ability of the U.S. workforce to remain internationally competitive depends upon the ability of U.S. workers to be efficient in multidisciplinary and technology-intensive settings.

Today's technology is not only enabling science, it is transforming science and all sectors of the economy that rely on science. For example, in the 1980s, the personal computer revolution placed computing at the average citizen's fingertips. In the 1990s, the internet revolution provided connections with an information web that spans the planet. This millennium is ushering in the next revolution that is connecting the internet to the physical world; in effect, it is giving the world its first electronic nervous system [1]. With sensors all over Earth and in space (e.g., satellites, weather stations, ocean buoys), environmental changes can be monitored over time and space like never before. With the world population at 6.5 billion and growing, the corridors of hospitable living conditions can change rapidly—in a matter of minutes with a tsunami, over a matter of hours with a hurricane, or over a number of decades with sea level rise. Sensors, which embody all four of the trends in technology stated above, are able to monitor short-term and long-term changes on Earth and, when coupled with sophisticated models, can provide predictions about future environmental changes and be utilized as an early warning system.

The STEM (science, technology, engineering, and mathematics) community, with support from the National Science Foundation (NSF) and others, has successfully conceived, designed, and begun implementing several new observation systems that rely on sensor technology (see Table 1). In addition, seventeen federal agencies are currently planning an integrated, comprehensive, and sustained Earth observation system to address the nation's critical societal and economic needs. The Integrated Earth Observation System (IEOS) will process data from satellites, ocean buoys, weather stations, and *in-situ* earth observing instruments into advanced scientific numerical models and decision support tools that will provide new data products benefiting societies and economies worldwide. These new and visionary projects will enable longer-term sensing of the environment (see also Parsons, Stewart, Fortner, and Lichtenwalner, this issue).

Table 1. Examples of Observing Networks

Network	**Objective**
Oceans **O**bservatory **I**nitiative (OOI) / **O**cean **R**esearch **I**nteractive **O**bservatory **N**etworks (ORION)	Measurement of air-sea fluxes of heat, moisture and momentum; physical, biological and chemical properties throughout the water column, and geophysical observations made on the sea-floor.
National **E**cological **O**bservatory **N**etwork (NEON)	Biodiversity, biogeochemical cycles, climate change, hydroecology, infectious diseases, invasive species, and land use.
WATer and **E**nvironmental **R**esearch **S**ystems	Monitor water supplies of adequate quantity and quality for human use while preserving the integrity of aquatic

(WATERS) Network	ecosystems.

The education of the 21st century observational technology workforce will require not only an understanding of environmental sciences and other disciplines, but an ability to resolve complex environmental issues and the ability to communicate complex ideas to a broad audience of stakeholders (see Table 2). With this revolution, the need to educate more scientists, technicians, and engineers that can design, assemble, deploy, troubleshoot, share, and analyze sensor data will be tremendous. Sensors will be highly pervasive, and it will be increasingly important to create a workforce that can develop and maintain observational networks relying on sensor technology.

Table 2. Examples of Disciplines that Support Observing Networks	
Science	oceanography, meteorology, biology, geology, physics, chemistry, & more
Technology	information technology, remote sensing (e.g. HF RADAR, ROV/AUV) GIS, electronics
Engineering	electrical, mechanical, environmental, structural, software applications
Maritime Science	ship/platform building, marine operations
Mathematics	modeling, statistics
Communications	written, verbal, teamwork, customer relations, across disciplines and with diverse audiences (stakeholders)

Fostering these critical abilities requires diversification of learning opportunities. Developing and maintaining such a workforce will rely on innovative educational programs that prepare future workforce professionals at a variety of levels and in a variety of environmental and technical fields [3]. Proper leverage of information technology-enabled systems, tools, and services will be critical for addressing these training needs, while having a profound impact on the practice of science and assessment, engineering research, industry, and global citizenry.

COSEE is playing an important role in helping to prepare this workforce. A first step is to disseminate information about ocean occupations and necessary preparation. One of many efforts underway to provide accurate information (led by COSEE California and the MATE Center) is an ocean career website (www.oceancareers.com) that helps users find answers to questions such as:

- What careers allow me to work in and around the ocean?
- What knowledge and skills will I need to enter those careers?
- How much might I make and who will hire me if I have those knowledge and skills?
- Where can I go to acquire those knowledge and skills?
- Which professional societies can provide more information and guidance for the career I'm interested in pursuing?

A thirty-hour companion online ocean career course also is available to students and educators seeking career advice or better information for mentoring students.

COSEE will continue to play a leading role in the evolution of ocean workforce development by:

- Gathering and synthesizing the best information available to define and describe ocean-related careers, their relationship to the ocean economy, and present and future workforce trends (with emphasis on ocean science and technology occupations).
- Identifying barriers to participation in ocean-related occupations.
- Identifying gaps between what ocean-related employers want/need in their employers, contrasted with current education/training practices.
- Aligning ocean-related STEM education with employer needs.
- Identifying gaps in the education system where specific ocean workforce needs are not adequately addressed and develop a plan to specifically address existing gaps.

COSEE is proactively working to identify the connections between ocean sciences careers, the knowledge and skills required to enter these careers, and general workforce trends. This work will help facilitate much needed reforms in the preparation of workers for employment in the nation's ocean sciences workforce. Students who have access to complete and accurate information will be more empowered to take control of their education and make wise choices about the courses and programs they choose. Educational institutions can use this information to improve their programs of study by more closely linking the education and training they provide to the knowledge and skills needed for specific ocean sciences careers. Employers will benefit by having a large pool of appropriately-educated applicants. In the end, the educational system will be more efficient and responsive to workforce needs and the workforce will be more satisfied with their chosen careers.

References

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3. U.S. Commission on Ocean Policy (2004). *An Ocean Blueprint for the 21st Century. Final Report*. Washington, DC. ISBN#0-9759462-0-X.

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Photo Descriptions

MATE_MikeKelly.jpg Photo 1. A marine technician from Monterey Bay Aquarium Research Institute (MBARI) performs maintenance on an ocean observatory buoy. Photo credit: Courtesy of Mike Kelly, MBARI.

MATE_PolarSubhires.jpg Photo 2. Students build a Remotely Operated Vehicle (ROV) equipped with a multitude of sensors for MATE's International ROV competition focused on Ocean Observing Systems. Photo credit: Courtesy of Patrick Endres.