# The Sensor Revolution:  Benefits and Challenges for the Marine Technology Workplace

Liesl Hotaling, Deidre Sullivan, and Jill Zande

***Abstract*** - Sensors are revolutionizing the way we study, explore and utilize our oceans. The continued development, operation and expansion of sensors and sensor networks will require a workforce well-prepared in science, technology, engineering and mathematics (STEM) skills, which are also critical to other sectors of the economy.  However, as national reports and international test scores indicate, these skills are currently lagging in U.S. students, presenting a challenge to the technology workplace. Using sensors and the data they produce as an engaging mechanism to teach STEM skills is one way to meet this challenge. Students armed with these skills can, in turn, put them to use in jobs that involve sensor development, operation and data use, providing lasting benefits to society and the global economy.

## I. Introduction – The Sensor Revolution

Technology revolutions have enabled science, industry and military applications and transformed society. In the 1980s, the personal computer revolution placed computing at the average citizen's fingertips and permeated virtually every sector of the economy. In the 1990s, the internet revolution provided connections with an information web that spans the planet. This decade has ushered in the next revolution, one that is connecting the internet to the physical world; in effect, the sensor revolution is giving the world its first electronic nervous system (National Science Foundation, 2005).

With sensors deployed and installed on the Earth and in space (e.g. satellites, weather stations, ocean buoys), environmental conditions are monitored 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. Sensor networks are able to monitor short-term and long-term changes on Earth and, when coupled with sophisticated models, can be utilized as an early warning system and to predict future environmental changes. Real time data produced by sensor networks can significantly impact decision making in research, military, business and government. For example, scientists can select optimum locations to deploy instrumentation, ships can steer clear of storms, offshore oil and gas companies can determine production schedules and governments can issue evacuations from a threatened area.

**A. Sensors in Society**

The use of sensors in modern society is increasingly pervasive. From highly sophisticated medical applications to self-flushing toilets, examples of sensors in society surpass any one discipline or industry. The wide range of applications and interdisciplinary nature of sensor research can have interesting and surprising results. For example, researchers from the University of Glasgow and Shell Global Solutions (Hirst, et al, 2004) teamed up to design a sensor to detect ethane as a method of identifying oil and gas deposits, which leak trace amounts of hydrocarbons. Medical researchers from the University of Dundee saw a connection to medical research, which had revealed that as part of its response to cancerous cells, the human body produces small amounts of ethane that can be detected in the breath.  Medical, geological and physics researchers teamed up to repurpose the technology into a quick and non-invasive screening tool for detecting lung cancer.  Many such innovations are a result of interdisciplinary, collaborative research.

**B. Observing our ocean**

Marine research increasingly relies on the convergence of traditional marine disciplines and technology.  For example, comprehensive large-scale studies in areas such as marine fisheries and El Niño require multidisciplinary approaches with technology playing a key role.  The rapid distribution of real time and forecast information to informed user groups (researchers, technicians, stakeholders, emergency management decision makers) and non-expert audiences (general public, stakeholders) is critical to navigation and prediction of seasonal events and ocean climate, and can be integrated into early warning systems for coastal floods, tsunamis, hurricanes, dams, energy consumption, beach closures, harmful algal blooms and more.

**C. Use of sensors in industry**

Sensors are used extensively in the marine industry. Embedded sensors in ship hulls is an example that integrates multidisciplinary research from the construction and aerospace industries. Hull sensor monitoring systems have a number of applications, "which can be summarized in the context of the lifecycle of the vessel, starting with a full-scale verification of the structural design and the building process and ending with retirement when the hull shows fatigue (Wang, et al. 2001)." These embedded sensors have significantly improved the understanding of stresses and strains sustained by the hulls. The collection of real time data has enabled real time understanding of critical situations that may lead to hull failure. Naval architecture students, manufacturers and captains alike benefit from and utilize this knowledge by improving hull design, fabrication, operation and safety at sea.

**D. Military applications of sensor technology**

The military was an early adopter of sensor technology. Whether deployed by trained dolphins or underwater robots, the military has relied on sensors to gather sensitive and critical data to inform missions. Remotely operated and autonomous underwater vehicles (ROVs/AUVs) are examples of sensor technologies developed largely with military funding that have a number of civilian applications. For example, ROVs, AUVs and the sensors that they carry are used to map waterways, identify potential locations of oil and gas deposits and measure currents underneath the polar ice cap. Data collected by ROVs and AUVs have proven vital to ensuring safe navigation; providing heat, light, and mobility to the masses; and increasing our understanding of our world.

## II. Preparing the workforce for the sensor revolution

### A. The need for change

With the sensor revolution comes the need for a workforce that can design, build, operate, maintain and utilize data from sensor networks. However, the multidisciplinary, technology-based approach needed to ensure workforce preparedness is not always reflected in our educational programs (Sullivan, D., et al, 2006). Students who over-specialize in any one subject to the exclusion of others, or who have not developed appropriate technical knowledge and skills, may have difficulty finding a job upon graduation. The ability of a 21st century marine technology workforce professional to remain competitive relies upon an ability to perform effectively in multidisciplinary and technology-intensive settings.

The workforce needed to support the sensor revolution also requires an ability to analyze data; troubleshoot and think critically to resolve environmental issues; and effectively communicate complex ideas to a broad range of audiences (see Table 1).

**Table 1. Examples of Disciplines that Support Sensor Technology**

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

### B. Facing a STEM crisis and a graying workforce

Developing and maintaining such a workforce relies on innovative educational programs that prepare workforce professionals at a variety of levels and in a variety of environmental and technical fields (U.S. Commission on Ocean Policy, 2004). The incorporation of technology-enabled systems, tools and services is critical to addressing these training needs and improving

STEM skills.  These types of learning opportunities are especially critical since trends reported by the National Science Board show that there are not enough students in the pipeline today to support the STEM workforce of tomorrow (NSB 2003, 2004, 2006). This poses a significant limiting factor to the development and deployment of sensors and sensor networks, not to mention other sectors of the economy. The graying trend in the marine workforce adds to the urgency of training new ocean professionals (Piktialis & Morgan, 2003).

**C. Educational community response**

**1. Addressing workforce recruitment and career preparation**

Industry, military, government and academic research communities are responding to this crisis by encouraging their members to engage in continuing educational experiences.  The secondary education community is responding by developing academic programs and course offerings that focus on marine technical issues, including sensor technologies and data use. For example, Rutgers University is providing undergraduate and graduate students with hands-on training experience and operational oceanography credentials.

However, educational efforts must reach further down and up the pipeline to truly address the lagging STEM skills and workforce needs.  A wide range of engaging learning opportunities that encourage students of all ages to hone their skills and potentially consider a STEM career are required. A first step is to disseminate information about marine occupations. One effort focused on information dissemination is being led by the Centers of Ocean Science Education Excellence (COSEE) California and the Marine Advanced Technology Education (MATE) Center.  OceanCareers.com (www.oceancareers.com) is a web site devoted to answering questions such as: What careers allow me to work in and around the ocean?  What knowledge and skills will I need to enter these careers? How much might I make and who will hire me? Where can I go to acquire the necessary knowledge and skills? and Which professional societies can provide more information and guidance? Armed with this information, students can make informed decisions about their educational pathways, pursuing programs and learning opportunities that provide the skills and support networks for success in the global, technology-rich workplace.

The ocean careers web site is part of a larger effort by the MATE Center and others to develop and improve technical education by:

- Gathering and synthesizing the best information available to define and describe ocean-related careers and their relationship to the ocean economy and workforce trends.
- Identifying barriers to participation in ocean-related occupations.
- Identifying gaps between what ocean-related employers need in their employees and current education 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 developing a plan to address these gaps.

**2. Addressing the need for real world learning experiences**

Learning opportunities that integrate cutting edge technologies such as sensors into scenarios based on the high performance, technical workplace are important mechanisms for preparing students for the workplace and meeting workforce needs. Programs like the MATE Center's international and regional ROV competitions, the AUV competition coordinated by the Office of Naval Research and the Association of Unmanned Vehicle Systems International and the International Submarine Races, among others, provide these technology-based, real-world learning experiences for students from elementary through university levels. Designing and building underwater vehicles for a competition scenario not only involves a practical, working knowledge of math, physics, electronics, hydraulics and engineering; it also requires project management, teamwork, critical thinking and continual problem solving [Sullivan, 2003]. In addition, through technical reports, engineering presentations, and poster displays, the competitions promote the ability to communicate complex issues to an audience of technical professionals, fellow students and the general public.

From collecting organisms under the polar ice cap to preparing a subsea wellhead for oil production and installing ocean observatory sensor hubs on the seafloor, these competitions also pique student interest in STEM concepts and make learning exciting. Further, the involvement of working professionals in organizing and judging the events provides students with an excellent opportunity to make the connection between the classroom and a future career.

The integration of real time (real world) data into classrooms is another powerful mechanism to increase student interest in and understanding of STEM concepts. Members of the COSEE network, led by Rutgers University, the Stevens Institute of Technology, Woods Hole Oceanographic Institution and others, continue the development of K-12 classroom materials that integrate real time maritime data into existing science curricula in order to capitalize on the benefits and improve STEM skills. For example, students can use available real time water level, salinity, current direction and speed, wind direction and speed data to emulate the work of a harbor pilot to safely navigate a large ship through a narrow channel and under a bridge.

This activity not only challenges students to interpret real time data, it reinforces several science concepts in the context of a real world application. In addition, there are several documented educational advantages to using data in classrooms, such as fostering problem solving skills and demonstrating relevance, among others.

Technology-based and data-enhanced educational experiences are important tools for student learning. In particular, these types of learning experiences prepare and empower students to address real-world complex problems; develop students' ability to use scientific methods; teach students how to critically evaluate the integrity and robustness of data or evidence and of their consequent interpretations or conclusions; and provide training in scientific, technical, quantitative, and communication skills (NSF, 2002; Hotaling, et al, 2006). Further, students exposed to these learning experiences not only have a better understanding of the fundamental STEM concepts, their level of awareness of sensor technology and sensor networks also increases.

## III. Conclusion

Marine technology is constantly evolving. The sensor revolution is playing a large part in the current evolution of the field as well as having far-reaching effects on other sectors of the economy. The continued development, operation and maintenance of sensors and use of sensor information depends on a workforce with the ability to apply STEM and effectively communicate sensor data to a variety of stakeholders. The challenge is to ensure that students of all grade levels have the opportunity to learn in an interdisciplinary environment that presents STEM in the context of real world applications. By meeting this challenge, we will prepare our students for success in the 21st century STEM workforce, one that can support the sensor revolution that continues to provide benefits to society and the global economy.

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**Authors**

Liesl Hotaling is the Assistant Director of the Center for Innovation in Engineering and Science Education at Stevens Institute of Technology. She is a partner in COSEE Mid-Atlantic and specializes in educational projects supporting observing networks. Liesl.Hotaling@stevens.edu

Deidre Sullivan is the Director of the MATE Center at Monterey Peninsula College, a partner in COSEE California. MATE's mission is to improve marine technical education and increase the number of highly trained technical professionals who enter ocean-related occupations. dsullivan@marinetech.org

Jill Zande is the Associate Director and ROV Competition Coordinator for the MATE Center at Monterey Peninsula College. jzande@marinetech.org