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Environmental Aquatic Resource Sensing: Basic Sciences, Business Education, and Outreach

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Abstract: Freshwater resources are critical features of the landscape and are threatened by many phenomena (e.g., eutrophication, invasive species, climate change, acid rain). The importance of fresh waters requires that scientists continually improve their tactics and technologies for broader understanding. Increasing use of automated sensors to collect environmental data creates a need for training of environmental scientists. In this paper, we present case studies based on a doctoral training program. For each case study presented, the goals and overall recommendations for adaptation to other programs are discussed. Case studies were selected based on recommendations of external evaluators of the program, the perceived value of the particular case study to the overall program, and the desire to provide case studies that were illustrative of the primary objectives of the project. We conclude that training of scientists in this area requires a consideration of the technology behind the sensors, proper usage of this technology, the technology development process, data management, and technology transfer. In addition to sensor-specific attributes of our program, we also have gained insight into the process of professional development for graduate students and how students can work across disciplines and universities. Our key suggestion for achieving inter-disciplinary training is to give students a common problem to tackle and the tools to do so. To ensure that these efforts are successful, identification of a group leader and provision of an opportunity for bonds and relationships to develop is vital.

Keywords: *Sensors, freshwater, technology transfer*

Freshwater resources are critical elements for both global function and human survival. Lakes, rivers, streams, reservoirs, and wetlands fulfill an array of functions both ecologically and economically. Some functions are obvious – serving as sources of drinking water and recreation, as transformers and conduits of ecologically relevant materials, and habitat to a diversity of organisms. Freshwater systems shape our landscape, connecting and integrating our biosphere, serving as "arteries and veins" of the planet (Williamson et al. 2008).

Our dependence on freshwater ecosystems is absolute. Globally, fresh water represents a small percentage (less than 2 percent) of the Earth's surface area; this statistic provides a glimpse into its vulnerability and underlines the need to understand aquatic systems. Beyond these issues, scientifically, aquatic systems represent dynamic and integrative landscape components in which multiple biogeochemical and ecological processes happen in close spatial and temporal quarters.

Threats to aquatic systems (e.g., eutrophication, invasive species, climate change, acid rain) are numerous. Our reliance on the structure and function of fresh waters requires that scientists continually improve their tactics and technologies for broader understanding. New approaches are needed because of the spatial and temporal scales on which changes happen. Historically, most environmental studies focused on a specific range of scales but automated sensors allow a new perspective on biological, geological, and chemical processes of aquatic ecosystems. When applied to ecological issues, sensor networks provide increased spatial coverage and sampling frequency beyond what could be achieved conventionally (Porter et al. 2005). Thus, the field of aquatic science is on the verge of a transformation in which exciting new questions can emerge, and chronic threats

to global fresh water can be better addressed.

The increasingly prominent use of automated sensors to collect environmental data, and address the concerns noted above, creates an urgent need for 21st century training of environmental scientists. These scientists must be knowledgeable about: (1) the design and development of sensors for deployment, (2) hypothesis-driven application of sensors and sensor networks, and (3) management/analysis of the resulting large, complex data sets. The recent emphasis on sensor systems is reflected in national programs (e.g., GLEON, the Global Lake Ecological Observatory Network, NEON, National Ecological Observatory Network, Water & Environmental Research Systems Network), centers (e.g., NSF-funded Center for Embedded Network Sensing), and the literature (e.g., the special issue of Environmental Engineering Science, Vol 24, March, 2007).

Lakes themselves are valuable sensors in the landscape. As the lowest point in the surrounding landscape, they are particularly valuable sentinels of climate change (Williamson et al. 2009). More importantly, advanced sensors are critical for resolving the disproportionate impacts that short-term storm events have on lake ecosystems (Jennings et al. 2012; Sadro and Melack 2012), and can address spatial heterogeneity of lake ecosystems at novel time-scales (Van de Bogert et al. 2012).

As a result of this need, we developed a NSF-funded Integrated Graduate Education and Research Traineeship (IGERT) program to educate doctoral students about advanced sensors for freshwater science. The central theme of this program is: Inclusive, immersive student learning in environmental sensing; from a foundation in ecology and environmental science to sensor design and development to creation of sensor networks to analysis of data sets; accentuated with practical business experiences to develop environmental science professionals equipped for positions in academia, private, or the public sector. By the very nature of this topic and the IGERT program goals, this is an interdisciplinary educational project involving faculty and students from multiple areas of science (biology, ecology, microbiology, chemistry, physics, geology, geography). In addition, our program includes faculty and students from two universities, Kent State and Miami, so working together with individuals at a distant location was another aspect of our program. Baldauf McBride et al. (2009), in a study of science graduate students in a NSF GK-12 project, suggest that interdisciplinary graduate programs of this type are "urgently needed to ensure that future leaders of the scientific enterprise are well equipped with the tools to conduct science as skilled collaborators, to address the key interdisciplinary questions that arise from complex environmental challenges facing society, and to better communicate their science with diverse audiences well beyond their scientific peers." Below, we discuss specific examples from our project including those focused on graduate student training (which we define as acquisition of skills and knowledge for applied purposes related to sensor use and development) and education (which we define as a more general student development not focused on development of a specific skill set).

To organize this article, we are taking a "case study" based approach by highlighting below specific aspects of our program that have proven to be most valuable for achieving our goals. In addition, for each case study we provide insights into the pros and cons of each component and the ease with which the approach could be applied at other institutions. The case studies are discussed in the approximate order in which they were conducted. Figure 1 illustrates the order in which we have covered these topics as well as the format we recommend. Case studies were selected based on discussions with two external evaluators of the program (who interviewed faculty and student participants), the perceived value of the particular case study to the overall program goals, and the desire to provide case studies that were illustrative of the primary objectives of the project.

Case Study 1: Using Unfamiliar Tools to Address Scientific Questions

Specifics of Case Study: One of the central theses to our educational approach is to provide an opportunity for individuals to become quickly immersed in the scientific process using environmental sensors. A secondary benefit of

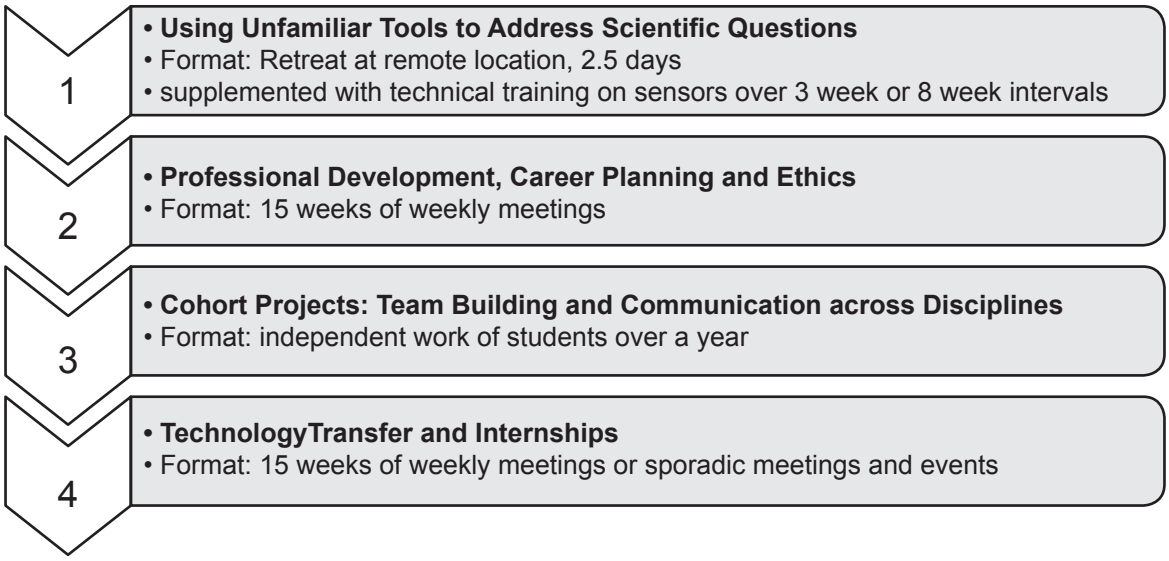

Figure 1. Order in which the various activities described in each case study (1-4) were implemented in our project and recommended format.

this immersion is the chance for students from diverse fields and backgrounds to get to know each quickly, minimizing the chance for distracting misconceptions of other fields to develop. The importance of the theme of this case study is three-fold: team-building, providing hands-on experience with sensor technology, and giving students a chance to ask and answer small-scale scientific questions. To accomplish this goal, faculty and students travelled to a remote field site far distant from our home institutions. This provides a location that is on 'neutral' ground (i.e., not at anyone's home institution) and removes the chance for distraction from day-to-day activities. Field trips are crucial aspects of student experiences in a variety of fields and Skop (2009) suggests that they provide an ideal opportunity to "foster informal interaction among students and faculty." Team building exercises, as described in this example, were among the best practices identified by Meléndez-Ackerman (2011) specifically with regard to IGERT programs.

In our particular case, we selected the Lacawac Sanctuary in Lake Ariel, PA because of specific properties which we argue will be helpful criteria for others in such situations. First, this is distant from our institutions but can be readily reached within a half day's drive. Second, it is located on the shores of Lake Lacawac and provides ready access to a field site with active and prior research (e.g., Tessier 1983; Williamson et al. 1997). Third, the site provides on-location lodging so participants not only work together during the formal schedule, but also interact over meals and after hours. The goals of this activity were (in no-particular order):

1. Team building and learning to work across universities and disciplines.
2. Learning about research of trainees and faculty.
3. Hands on activities with sensors.
4. Students posing and answering scientific questions and presenting their findings.
5. Meetings with assessment and evaluation team.
6. Planning for the remaining year and for future projects.

Below, we describe the manner in which we worked to achieve each goal.

The goal of team-building and learning to work across universities and disciplines is central to all aspects of our program. Thus, this first event helps to lay the foundation for future interactions. Providing a face-to-face opportunity for students to get to know each other and bond means that they will be able to stay in touch more easily after they depart to their respective universities. For our

ice-breaking activity, we have asked students to pair up with the person they know the least about, and then to introduce each other to the group. In this way, people that have never met and might be from different science disciplines can begin to understand the areas of research represented by the group. This exercise then lays the ground work for very short presentations on research interests and expertise given by each participant.

Perhaps the most important activity, after having gotten everyone acquainted, is to charge the students with conducting a short research project using sensors. This gives immediate hands on experience with technology that is not familiar to most participants, and provides them a chance to work towards a common goal. For example, students in several cohorts developed an interest in spatial variability of high frequency measurements of parameters, such as temperature, oxygen, pH, or conductivity. In one year, students examined vertical differences in the lake by deploying sensors at different depths at a single location. In another year, sensors were place is different locations but at a similar depth, essentially exploring different habitats (nearshore vs offshore). During these projects, students were exposed to sensor related issues, such as calibration, logging intervals, power consumption, field deployment, and occasionally technical difficulties (trial and error often being a very effective learning pathway). Collecting data at high frequency challenged the students by exposing them to a data set that was much larger than they might typically be used to handling. Extensive data analysis was limited due to time constraints, but students were asked to derive secondary information from their data, such as estimates of respiration that could be calculated from changes in oxygen overnight. In our most recent workshop, students were given access to a suite of advanced aquatic sensors and asked to document evidence of the response of lakes to recent climate events using vertical profiles of various physical, chemical, or biological factors. Ultimately, the students then presented their findings to the entire group, interpreting the "signals" of change in light, temperature, oxygen, chlorophyll, and other variables with depth in the water column. Since each group sampled a different set of variables, a lively discussion ensued.

While these activities are underway, participants also meet with outside assessors and evaluators who take advantage of the gathering to conduct individual interviews. Lastly, the plans for the coming year are discussed; these are described in more detail below.

Recommendations: Based on our experiences, we believe, for educational programs, that off-campus trips that require overnight travel provide an effective way to jump start a program and to form groups working towards a common goal. Proximity to a study site is also an advantage for studies on aquatic ecosystems. Disadvantages include costs and logistics. For the latter, the distance and time involved does inhibit the willingness and ability for faculty to participate.

Coincidentally, one year we were unable to complete the trip to Lacawac Sanctuary due to extensive flooding causing road closures on our drive to the location. While we were able to accomplish many of the goals by holding the event at Kent State, we felt that some of our goals were compromised, especially the formation of a cohesive group that seemed to have otherwise formed during after-hours activities (e.g., sitting around a campfire as opposed to returning to one's home or hotel room).

Case Study 2: Professional Development, Career Planning, and Ethics

Most of the efforts described in this paper are very much focused on student training that is pertinent to our particular theme. However, we became aware of other vital aspects of graduate student education where our program could further contribute. These aspects include professional development and career planning, as well as responsible and effective conduct of research and teaching. Originally these components were underdeveloped in our program, but as it evolved we included them as significant objectives to be met through two mechanisms. The importance of the theme of this case study is that it focuses on one very central aspect of graduate training, responsible and effective conduct of research, that are widespread in programs of this type.

First, we used a series of university-wide workshops (1-2 hours each) that would appeal to the broadest student audience. Topics of these workshops included applying for fellowships, careers in academia, business, and government, manuscript writing, etc. Each workshop featured a speaker with expertise in a particular area, including those that were recently on the job market.

Second, we unified these experiences into a formal course. The reasoning behind formalization was two-fold. While the informal workshops were effective and very well attended, they were difficult to schedule at a time that worked for students in many different departments. In addition, students were not required to attend and because it was informal there was no opportunity for work outside the meeting. With the formal class approach, we have a set weekly meeting time and students can complete assignments outside of class. For example, they can prepare their CVs and share them with their peers. In addition, faculty have provided us with grant proposals for mock review panels. Other topics include appropriate conduct in the laboratory, issues related to manuscript preparation and submission, etc.

Recommendations: Formalizing these activities provides us more opportunity to ensure each student comes away with the tools they need for their future careers. Invariably, writing and speaking are parts of their futures and we work to provide them these experiences in a content-independent manner. Many content specific classes require, for example, students to write a proposal but likely do not cover the true nature of the funding process or provide examples of successful and unsuccessful proposals that were actually submitted by faculty.

Case Study 3: Cohort Projects: Team Building and Communication across Disciplines

The relationships among the students developed during the off-campus retreat are vital to laying the groundwork for their "cohort" project. The idea is to build upon the model of case study 1 (getting students working together towards a common goal) over a longer time frame to achieve more valuable products. There are two central themes of this case study: having student learn to work across disciplines and conducting inter-disciplinary research. This approach has the added benefit of providing students insights into the conceptual framework and 'way of thinking' about science used by those in different fields. The cohorts are composed of students who entered the program at the same time but who are from different scientific disciplines and universities. In this way, the theme of working across fields and campuses is further reinforced. It is important to note that students have to find common language through which scientific exchange can occur, as discipline-based trainings often set jargon boundaries. For example, the word "director" has a specific meaning for chemistry and physics students, that may not be evident to the other science students. Furthermore, ecology students are often well versed in the differences between a "buoy" and a "sonde." Yet, their distinction is not readily evident to most bench scientists. Thus the cohort-building process forces students to familiarize themselves with the science of their new colleagues, enlarging the breadth of their science base.

Another aspect of the cohort project is to give the students a chance to creatively come up with a project that is related to our theme and that takes advantage of their expertise. We start this process by having students from prior cohorts talk about their experiences and offer tips to the new students. These meetings happen during the initial workshop describe above in case study 1. We then provide opportunities for the cohort to brainstorm, giving them access to faculty who answer questions and help the discussion stay focused, but who do not influence the project design. In this regard, each cohort has "ownership" of their project.

There is a gradient or continuum of inquiry based learning approaches; Bonnstetter (1998) describes this continuum as ranging from carefully scripted work to open, student-driven work. This case study represents the latter end of this spectrum which is described by Lee (2012) as "an inquiry experience, perhaps student designed, through which students acquire content relevant to the inquiry and further develop the skills of inquiry."

The types of projects that have been completed are variable. The first group of students developed an educational web page with support from a sensor-related company. This activity provided

them a means of achieving a goal of public education while at the same time working with a business. The latter is central to one of our themes and is developed more below. This web site is called The Lake Scientist (www.lakescientist.com). Working with a company allowed the quality of the web site to be high and to help make sure it would be maintained over time. The second group of students followed a similar line of reasoning but was less successful in making their materials available to the public.

The third cohort is working on two projects. One group is working on development of a liquid crystal based sensor for microcystin, a cyanbacterial toxin. Another group is working on examination of dissolved organic carbon based on optical properties across a range of aquatic ecosystems.

Recommendations: Group or cohort projects are typical components of educational efforts but can have pitfalls. Perhaps the biggest question we face is: what is the role of faculty in the process? In other words, what is the proper amount of guidance to give the students? A balance needs to be struck between allowing the students full independence and creative license, while promoting a project that extends into the realm of broader impacts for science, education, or personal career advancement. Ultimately, the most important goal is to help make sure that their efforts do not derail and that lines of communication remain open and active. For our own program, cohorts in which there was a single individual with strong leadership qualities were more successful than when the leadership was not clear (more than one leader or no one actively assuming that role).

Case Study 4: Technology Transfer and Internships

Often times, scientists use sensor technology daily but may not be aware of the process that leads up to an invention or development of a new product. However, any time we are working on projects that involve technology there is often technology transfer that underlies the product. In addition, a number of students in our project are in the field of sensor development and the products of their efforts likely include patents. Thus, learning the rights and responsibilities, as well as the mechanics, for protecting intellectual property are vital. To this end, we discuss the requirement to document ideas, communicate novel approaches, and suggest applications. These actions define "inventorship" and become helpful in the assignment of patent claims. The importance of this case study relates not only to understanding invention and entrepreneurship but also serves as carrier preparation for students planning on working in the private sector.

We have approached educating students about the business side of science in two ways: internships and seminar-style courses or workshops. Internships can impact the individual student in a profound, transformative way. While the student may share their experiences with others, the learning potential does not extend far beyond the individual. In addition, not all internship experiences are equally positive. In contrast, seminars and presentations provide a way to provide a more general learning experience to a larger numbers of students.

For internships, the goal of our project was for the experience to be consistent with the career interests of the students. In one case, students worked with a Kent State University (KSU) spin-out company, Crystal Diagnostics. This company uses patented liquid crystal sensor designs to detect bacteria and viruses in real time. Students learned the process of product development and methods of scale-up. Included in their "business-world exposure" are the critical roles of quality control, good manufacturing processes, and regulatory compliance issues. In a second example, Miami University students interned with Fondriest Inc. and NexSens Inc, where they are in the process of developing cutting edge technologies for both mobile buoys and buoys that can do automated vertical profiling with a winch that can be controlled from a smart phone.

Another way to educate students about this aspect of sensors is through visits to companies, seminars and presentations. For example, groups of students visited Crystal Diagnostics and company presidents have presented seminars at our campuses. In addition, we've used university resources to help this process. The Kent State University Associate Vice President responsible

for technology transfer, commercialization and marketing, as well as the university lawyer overseeing patents and copyrights, presented the process by which ideas are protected, especially those coming from academic institutions. This not only accomplishes the goal of exposing students to this process it also gives them insight into the inner workings of the university.

Other individuals have also been tapped to help us meet these goals. These include faculty inventors and faculty within our colleges of business, as well as local entrepreneurs. The use of specific seminars and presentations allows groups of students to learn directly from these individuals.

Recommendations: Our observations suggest that many students and faculty are not familiar with technology transfer and entrepreneurship. Internships provide a great manner to gain this experience but can be very time-consuming and do not necessarily include specific learning objectives, such as intellectual property. Internships also require the institution and its partners to take on additional management responsibilities. Taking advantage of resources offered by the technology transfer office, which most major research universities have, provides a simple way to help meet at least a portion of these educational goals without the time and resource commitment of internships. Our experiences have shown that the missions of the offices involved are very consistent with our educational goals and that they are capable of providing valuable experience and assets to assist in our training.

Conclusions and Recommendations

To describe our inter-disciplinary graduate student training program, we use a case study based approach to highlight specific approaches used to achieve educational goals. Case studies, selected based on criteria described in the text, illustrate the manner (using specific examples) our goals were achieved and provide ideas about the strengths and weaknesses of each example and transferability to other institutions and settings. Our particular program, which focuses on sensors, is built upon the premise that sensors are an integral part of freshwater science and training of scientists in this area requires a consideration of multiple factors: the technology behind the sensors, proper usage of this technology, the process by which new technology is developed, data management, and technology transfer. In addition to sensor-specific attributes of our program, we also have gained broader educational insights into the process of professional development for graduate students and how students can work across disciplines and universities. The key to achieving inter-disciplinary training, in our view, is to give students a common problem to tackle and the tools to do so. To ensure that these efforts are successfully launched, identification of a group leader and providing an off-campus experience to allow bonds and relationships to develop is vital.

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Darren L. Bade's research focuses on the interaction of the chemical and biological components of lake ecosystems. Some of these interactions are studied in a traditional way and may have distinct applied components. For example, his research addresses questions such as, what elements limit the growth of

phytoplankton in lakes, or how do ammonia-oxidizing bacteria contribute to dead-zones in lakes? Further understanding to the fundamental aspects of lake ecosystem ecology are derived from his research using automated sensors and buoys. An emerging topic in his lab considers how spatial heterogeneity within a lake can influence the ecosystem-level metabolism of lakes. Sensors become a necessary tool for this endeavor, but his findings also shed light on how to most effectively use sensors to gather the most meaningful information in lakes. He can be contacted at: Department of Biological Sciences, Kent State University, Kent, OH 44242, dbade@kent.edu.

Jon Scaffidi received his Ph.D. in analytical chemistry from the University of South Carolina in 2005. Following post-doctoral appointments at the University of Pittsburgh and Duke University, in 2011 he joined the department of Chemistry and Biochemistry at Miami University in Oxford, Ohio. The Scaffidi lab's research focuses on the development of improved tools and techniques enabling rapid remote, on-site and in situ analysis—in essence, "taking the laboratory to the sample" in environmental, biomedical, industrial and security applications. Can be contacted at: Department of Chemistry and Biochemistry, Miami University, Oxford OH, scaffijp@muohio.edu.

Craig E. Williamson As a global change limnologist he focuses on lakes as sentinels of climate change. As the lowest point in the surrounding landscape, lakes are hotspots that are sensitive to both natural and anthropogenic disturbances in terrestrial, atmospheric, and aquatic environments at the local, regional, and global scales. Lakes provide signals of change in their highly responsive plankton populations. He uses advanced optical instrumentation to assess the role of changes in transparency in the structure and function of lake ecosystems, with an emphasis on the causes of changes in ultraviolet transparency and their consequences for higher trophic levels (zooplankton and fish). He can be contacted at: Department of Zoology, Miami University, Oxford, OH 45056; willia85@muohio.edu.

Christopher J. Woolverton Microorganisms play a critical role in the health and disease of planet earth. Their detection using deployable sensing systems is one way to monitor their impact. As a microbiologist concerned with the impact of microorganisms on human health, he has partnered with colleagues in various areas of science to view this problem from viewpoints well beyond his own. Together they have invented new ways to sense microorganisms using the science behind liquid crystals. Rewarded in these efforts, he seeks to help students move outside of their discipline silos to experience the fruits of interdisciplinary collaboration. Can be contacted at: Department of Environmental Health Science, Kent State University, Kent, OH 44242; cwoolver@kent.edu.

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