

## COMMENTARY

# The Lake Ontario Great Lakes Science Practicum: A Model for Training Limnology Students on How to Conduct Shipboard Research in the Great Lakes

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**ABSTRACT.** *The authors designed and led an 8-day limnology practicum conducted on the R/V Lake Guardian that focused on classical and emerging technologies in a series of four inter-dependent teaching modules. The practicum was tied together by a general research question (Are spatial patterns of Lake Ontario productivity a function of distance from the shoreline?), and a guided inquiry approach was used to help students frame testable hypotheses to address this question. Students collected a research-quality data set while participating in the practicum's teaching models, and subsequent to the cruise presented their results as oral papers at research conferences and as research papers. The design of this practicum may provide a useful model for other educators who wish to train the next generation of Great Lakes limnologists by conducting courses on a research vessel.*

**INDEX WORDS:** *Inquiry teaching, education, limnology, Lake Ontario.*

## INTRODUCTION

To meet the challenges of aquatic sciences and the demands on fresh water in the 21<sup>st</sup> century, there is a pressing need to train freshwater aquatic scientists (NRC 1996, Wetzel 2000). A recent review of the state of freshwater sciences in North America has identified the need for limnology to be

taught more widely in university curricula (ASLO 1999). Despite the size, proximity to large universities, and importance of the Laurentian Great Lakes, research on pelagic regions of the Great Lakes is not often done, in part because of logistical constraints related to working on a ship. In fact, shipboard research activity appears to be declining in the Great Lakes, as indicated by a decrease in the proportion and absolute number of papers presented

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at annual meetings of the International Association for Great Lakes Research<sup>1</sup>; as a consequence, fewer students are provided the opportunity to become involved in shipboard research.

To meet the need for the training of Great Lakes limnologists, the United States Environmental Protection Agency Great Lakes Program Office (USEPA GLNPO) has offered ship time to qualified university faculty for use as a platform for instruction. In 1993, the R/V *Lake Guardian* was first offered as a floating classroom at low cost to individual students. Professors from three universities taught 18 students in a multi-disciplinary approach expanding their practical knowledge in the general area of limnology. Upon evaluation of the success of this first endeavor, the USEPA GLNPO has requested, on five separate occasions (through 2004), proposals from Great Lake institutions for use of the R/V *Lake Guardian* to conduct educational courses on the Great Lakes designed to teach undergraduates, graduate students, or teachers about the physical, chemical, and biological components of the Great Lakes ecosystem. Nine of the ten offers made by GLNPO were accepted, and courses were given in each of the Great Lakes: Lake Superior (2), Lake Michigan (2), Lake Erie (2), Lake Huron (1), and Lake Ontario (2).

A general goal of GLNPO is to develop and enhance interest in the general field of aquatic sciences, and about continued stresses to the ecological balance in the Great Lakes. Shipboard classes facilitated by the resources of GLNPO are viewed as a cost effective means of education in Great Lakes science, conservation, and outreach. At least three educators currently teaching at Great Lakes universities were students in the 1993 course (including the corresponding author of this article). In 2002 alone, sixty high school teachers were trained to bring Great Lake science curricula back to their classrooms, reaching an estimated 1,200 students, and perhaps inspiring some to select careers in limnology or related fields. The cost of this training is less than \$5 per student if the teachers continue for 3 years to use the Great Lakes teaching units they developed.

In 2003, USEPA GLNPO allocated ship time onboard the R/V *Lake Guardian* to conduct limnology

courses on Lake Ontario. In this paper, we describe an intensive field course that was designed to provide students the opportunity to learn basic limnological principles, participate in the collection of a research-quality data set, gain knowledge of environmental issues pertinent to the Great Lakes/St. Lawrence River system, and learn the practical aspects of living and working on a research vessel. We used a hybrid problem-based learning and guided inquiry approach to teaching limnology: faculty proposed a general research question, taught students some methodologies to collect data relevant to answering the question, and tasked students to gather key data throughout the cruise. Students were required to propose specific hypotheses related to the general research problem, and then analyze the data collected during the cruise to evaluate their hypotheses. Our curriculum was designed to apply two "student-active" approaches to learning, inquiry and problem-based learning, which are being increasingly advocated by educators as effective innovations for teaching ecology and other sciences (D'Avanzo 2003a, 2003b). The primary objective of this paper is to provide a model for a successful limnology practicum aboard a research vessel, by applying problem-based learning and guided inquiry approaches, which can be used by other instructors when planning similar courses.

## COURSE DESCRIPTION

An intensive 8-day field practicum was conducted 19–26 September 2003, on Lake Ontario. Students obtained practical and theoretical knowledge of Great Lakes limnology by working in small groups (2–3 students) on two topics per day with a rotation of topics and partners every 2 days. The course was offered by Clarkson University. The course assumed knowledge of general chemistry, and was appropriate for biology, chemistry, and environmental engineering majors, and other students with a serious interest in environmental science. The course was designed for upper level undergraduates and beginning graduate students, and provided dual undergraduate-graduate credit.

## Application Process

Students were selected on the basis of interest and aptitude. A statement of current interest in Great Lakes science and future plans was requested along with an official academic transcript. Letters of reference helped to ensure that the students ap-

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<sup>1</sup>In 1980 at the IAGLR-Kingston conference a total of 181 papers were presented with 29% reporting on studies that dealt with offshore limnology requiring a large vessel or buoy. In 2001, at IAGLR-Green Bay, 412 talks were presented with 17% involving large vessel work, and in 2004, at IAGLR-Waterloo, of 411 papers, 13% involved large vessel use.

plying to the course were prepared for the rigors it entailed. Based on aptitude and interest, we selected seven participants, including four undergraduate and three graduate students. Several other potential applicants to the program were unable to attend due to the scheduling of the course that took place during the fall semester period and required absence from regular classes.

### Content Module Design

The cruise curriculum focused on using both classical sampling methodology and advanced molecular biological techniques, to test the general question of whether biological productivity in Lake Ontario is strongly influenced by shore zone processes. The instructional modules were designed to provide the students with fundamental limnological theory and a sound practical knowledge of limnological techniques and protocols appropriate for pelagic research on large research vessels. We focused on techniques that are suited for use onboard the ship to provide real-time measurements. Our objective was for students to design a sampling strategy to measure biotic and abiotic water quality indicators along a transect using appropriate techniques, with an awareness of logistical constraints to sample collection and analysis.

The cruise track went from Fort Niagara, New York, east to the mouth of the St. Lawrence River, where station sampling commenced (Gouvêa *et al.* unpublished manuscript). Over the next 6 days, a series of evenly distributed north-south transects was sampled as the ship moved west back to Fort Niagara. A total of 32 stations was sampled by the practicum students.

To attempt to answer our general practicum question (*Is biological productivity strongly influenced by shore zone processes?*), participants measured along repeated shore to mid-lake transects: (1) physical characteristics of the water column, (2) concentrations of the limiting nutrient phosphorus, (3) biological demand for phosphorus, (4) phosphorus bioavailability, (5) density of bacteria, (6) density of viruses, (7) size-class density of phytoplankton, and (8) abundance and dispersion of pelagic waterbirds. All modules were interdependent in order to provide a valid, holistic answer to our main research question, and to emphasize how team effort and multidisciplinary approaches are necessary for working on a large aquatic system such as Lake Ontario. Module activities included observational data collection and manipulative ex-

periments. The four modules are described in more detail in the following sections.

### Physical and Chemical Limnology

The abundance and distribution of biota in a lake are a direct function of the interplay among chemical and physical factors. Understanding microbial dynamics in a lake, and the impact this has on higher trophic levels, requires a considerable knowledge of abiotic factors present in the water column. Fundamentals of water column characterization were taught through the use of physical and chemical analysis of water throughout the water column via automated sampling (integrated conductivity-temperature-depth [CTD] probe) and discrete sampling techniques (Rosette sampler). Physical limnological concepts (e.g., diffusion, water movements [currents, waves], heat budgets, light transmittance, sedimentation) and chemical limnological concepts (e.g., chemical speciation, ionic composition, dissolved organic matter, particulate matter) were discussed in relation to their impact on organisms. Hands-on module activity involved: 1) CTD profile interpretation; 2) light extinction coefficient measurements; 3) discrete water sampling (using Niskin bottles on the rosette water sampler); 4) large volume filtrations using trace metal clean protocols; 5) water sample analysis in the chemistry laboratory, e.g., chlorophyll *a* and phosphorus; and 6) sediment sampling using a box corer for characterizing sediment surface properties and for collecting benthic invertebrates (demonstrated by USEPA and NOAA personnel).

### Phytoplankton Physiology and Ecology

Phytoplankton respond to changes in environmental parameters through the induction of specific protein and enzyme systems. As such, the cells themselves often serve as informative sentinels of environmental quality. Nutrient deficit, in particular, is reflected in the induction of specific proteins that allow the cell to better compete for scant nutrient resources. This module introduced students to some of the approaches used to assess phytoplankton nutrient status. Techniques examined onboard the ship were: 1) fluorometric analysis of ectoenzyme activity and kinetics (alkaline phosphatase), and 2) the use of luminescent whole cell bioreporters to assess bioavailability in aquatic systems (using a P-dependent cyanobacterial bioreporter (Gillor *et al.* 2002).

### Bacterial and Viral Ecology/ Harmful Algal Blooms

The major goal of this module was to help the students gain a better appreciation of the microbial component of Lake Ontario. Although limited by time constraints, participants undertook a series of basic measures along the cruise transects to develop an appreciation for microbial interactions as well as the influence that microbes may have on human activity. As such, four specific objectives were pursued: 1) the enumeration by fluorescent microscopy of the total viral and bacterial load at each station (sampling was conducted onboard the ship, whereas counting was conducted on shore); 2) the isolation of specific microbes of interest to human health issues; 3) the isolation of microbes important in the dynamic of the lake's carbon budget; and 4) the isolation of viruses specific to lake microbes. Students learned and practiced basic aseptic techniques.

### Dispersion of Pelagic Birds in Relation to Lake Productivity

This module focused on the distribution and abundance of Great Lakes pelagic 'waterbirds', birds that forage offshore (Langen *et al.* 2005). Waterbirds are important indicators of environmental health in the Laurentian Great Lakes ecosystem, since their abundances are affected by biomagnifying toxic compounds, successful introduction of invasive exotic species, shoreline land-uses, and the presence of infectious pathogens. By participating in this module, students learned how to (1) make valid population density estimates using transect counts, (2) describe dispersion (e.g. clumped, random or even distributions of individuals), and (3) identify common pelagic bird species present on Lake Ontario.

### Scheduling

The practicum followed the same daily schedule regardless of weather (Table 1). The schedule provided for two 4-hour modules on a different topic each day, and a 2-hour seminar each evening, for a total of 74 hours of formal instruction. Students worked their way through all four modules over a 2-day period, then repeated the four modules with another student partner(s). Each module was thus designed to have each student participate four times over the 8-day practicum.

**TABLE 1.** Daily activity schedule for the Lake Ontario Limnology Practicum Opportunity (LOLIPOP)—19–26 September 2003. Students participated in two different modules each day and completed the module rotation every 2 days.

Time	Activity
05:30–06:30	Breakfast
06:30–07:30	Health break
07:30–11:30	Morning modules
11:30–12:30	Lunch
12:30–13:30	<i>Pause santé</i>
13:30–17:30	Afternoon modules
17:30–18:30	Supper
18:30–19:00	<i>Repos</i>
19:00–21:00	Evening seminar

### Evening Seminar Series

An evening seminar series was used as the main format to ensure that all students were provided content on basic limnological principles, and on major environmental issues pertinent to the Great Lakes. Each instructor delivered a seminar: Hydrology and limnology of Lake Ontario (Twiss), Food web theory (Langen), Microbial ecology and food webs (Wilhelm), Bio-reporters for monitoring ecosystem health (Bullerjahn). In addition, three scientists from the USEPA contributed topical seminars on anoxia in Lake Erie (Rockwell), the Lake Ontario lake-wide management plan (F. Luckey), and atmospheric deposition of contaminants to the Great Lakes (T. Nettesheim). At one port of call at the head of the St. Lawrence River in Clayton, New York, the students participated in a discussion on controversial upper St. Lawrence River and Lake Ontario policy issues with a representative of an influential regional environmental advocacy group (S. Weiss, Save the River).

### POST-COURSE ANALYSIS

#### Rationale and Advantages to Our Curricular Approach

One common approach to a field limnology course is the lecture tour, in which an instructor brings students to interesting locations and discusses concepts that the locations help illustrate. This approach is efficient at delivering content knowledge, but is poor at teaching limnological techniques or methods of scientific inquiry. A second type of field limnology course is the pure practicum approach, in which the instructor focuses

on teaching students how to perform various important techniques that are commonly used in limnological research. This approach is useful for teaching research methodology, but is poor at improving content knowledge about limnology or the logic of scientific inquiry. A third approach is to focus on free inquiry. The instructor develops students' skills at formulating a testable hypothesis about anything of interest to them, and at designing and completing valid research projects that answers the students' research questions. This approach is quite effective for improving student understanding of the logic of scientific inquiry, but is poorer at improving content knowledge or technical skills important for authentic limnological research. Currently there is much interest in investigating the strengths and limitations of each approach to teaching environmental sciences, as part of a general movement to reform college teaching practices in the sciences and other fields (D'Avanzo 2003a, 2003b).

We took a hybrid approach, incorporating aspects of each of the three of the approaches described above, with the goal of improving all three aspects of our students training: content knowledge, technical skills, and understanding of the scientific process. Evening lectures and assigned background readings provided the main venues for improving students' content knowledge. The modules were designed to teach the limnological techniques. We addressed students' understandings of the scientific process by tasking each student to formulate a testable hypothesis related to the main theme of the cruise, and to test the hypothesis using relevant data from the accumulated cruise data set.

By having a general research question as an overall theme of the cruise, we intended to help students understand the interdependence of the four modules, and how very different approaches can complement one another at understanding complex limnological systems. A thematic approach to the limnology practicum enhanced the connectivity among the different modules. Modules were interdependent, meaning that results from the other three modules helped at interpreting the data of each. For example, relating P bioavailability of a bioreporter to the amount of P detected chemically in the water, assaying phytoplankton community responses to P enrichments to changes in enzymatic activity involved in phosphorus utilization, and determining correlation between aquatic bird abundance and phytoplankton biomass in waters along the census transects.

The modules were designed to allow students to repeat tasks several times, in order to achieve skill mastery. The 1-week cruise length provided ample time for students to become familiar with the techniques yet not be overwhelmed by the need to acquire techniques rapidly or become fatigued from overly repetitive tasks. As the cruise went on, students spontaneously began to multi-task; when there was a break in the duties for one module, students pitched in and helped on the others.

Scheduling of the modules provided for contact of each student with others in the practicum. Each student worked with one (or two) other student(s) as they cycled through each of the four modules over 2 days. The student then worked with another group of students as they began the module repetition. The schedule was tightly adhered to so that students were always aware of their required activities even at times when inclement weather prevented module activities, as occurred twice over the duration of the cruise caused by the passing of the weather system associated with Hurricane Isabel. Students had no break from the modules, but the schedule was such that each faculty member had one break during the 2-day, four-module cycle. This break proved to be very useful, as it provided time for equipment repair, data review, and lecture preparation.

The R/V *Lake Guardian* is an excellent platform to support our practicum design. The practicum modules took full advantage of the available facilities: CTD/rosette sampler, environmental growth chambers, all ship laboratories, autoclave, fume hoods, and navigational aids. Equipment brought onboard by the faculty was limited to an epifluorescent microscope, two fluorometers, a spectrophotometer, a luminometer, and binoculars and spotting scopes.

The activities of the USEPA and Environment Canada personnel involved with the Lake Ontario Lower Food Web Analysis (LOLA) project onboard the ship during the cruise greatly improved the practicum experience. Students were able to observe sampling protocols for zooplankton and benthic macroinvertebrates, important limnological activities that were not directly covered in the students' modules. More importantly, the students were able to see research scientists conducting limnology, using methodological and conceptual approaches similar to those covered in the modules.

All faculty involved in the practicum had field experience. The importance of field experience cannot be overstated since it provided a depth of expe-

periences that could be related to the students when explaining the basis for selecting sites and when explaining the reasoning behind decisions to change the cruise plan en route due to weather conditions. In addition, complementary expertise among the faculty was considered an asset to both the design of the modules and strengthening the linkages amongst them. Sharing of module content (hand-outs, protocols, seminar content) among the participating faculty and members of the LOLA study group prior to the cruise helped coordinate usage of space and enabled smooth transitions from module to module. The faculty and USEPA personnel met at the International Association for Great Lakes Research conference prior to the cruise, which provided an informal forum for discussing the logistics of sharing the research platform.

#### Course Products and Student Assessment

At the end of the cruise, the instructors collated the data collected during the modules into a comprehensive data set that was distributed to the students. Each student was required to write an independent research report testing a specific hypothesis related to the general question of whether Lake Ontario productivity is related to proximity to the shore, using the data collected during the cruise. Students could focus on a set of data collected during one module, or choose to attempt to incorporate the entire data set into a report. All faculty members read each report. The consensus of the faculty was that the quality of the analyses and conceptual understanding of the results, as evidenced in these reports, was generally high.

We encouraged the students to present their findings at a regional conference, the Great Lakes Research Consortium Annual Student/Faculty Conference, Syracuse, New York (March 2004). Five of the seven student participants in the practicum contributed four oral presentations, held in a special session devoted to this limnology practicum at the conference. Some of the students combined their analyses to draft a research publication, which has been submitted in collaboration with the instructors to a research journal (Gouvêa *et al.* unpublished manuscript). These oral presentations and written publications provide the best evidence, in our opinion, that the students were provided with an authentic experience into conducting scientific inquiry during our limnology practicum.

#### Strategies for Expanding and Refining the Course

There are logistical constraints to offering the practicum described above for a class greater than 15 students. Hands-on experience is prerequisite to learning the skill set in this practicum and repetition of these skills is required for mastery. More than five students in a module team would compromise the ability of the students to remain actively engaged by the instructor in the module exercise. Moreover, a group of 15 students and the 4 instructors is the maximum that can be comfortably accommodated in the galley of the R/V *Lake Guardian*, where seminar presentations and group addresses are made.

Our practicum could have been improved by scheduling more time to formally inspect and interpret the data set together as a group. One meeting on the eve of departure did not allow ample time to assist the students' skills at analyzing and synthesizing the results embedded in a large, multifaceted data set. Two possibilities to achieve this refinement are either using a portion of each evening seminar period to report on module activities, or convening a post-cruise workshop. The advantage of the evening module reports would be to link modules that carry over to multiple days (e.g., grow-out experiments, long-range transects) so that the new module rotation group will be adequately prepared for the next day's work. A post-course workshop would have the benefit of providing the time to reflect on the achievements of the cruise, and would provide a less distracting environment to critically analyze and synthesize the data. Ideally, the group would meet in a shore-based conference center. Although the ship in port could be used for this purpose, it is not a good use of the ship's resources.

#### SUMMARY

1) We recommend that the template for a successful limnology practicum based on the use of the R/V *Lake Guardian*, or similar sized research platform, over a 1 week period requires a thematic approach with complementary faculty expertise.

2) It is reasonable in a limnology field practicum to have objectives that include improving general content knowledge about limnological concepts, mastering limnological research techniques, and deepening understanding about scientific inquiry. Students should repeat interdependent practicum modules several times during the cruise in order to achieve competence in skills covered during the

week. A formal evaluation procedure to assess pre- and post-practicum knowledge would be an asset for judging the effectiveness of the curriculum at increasing content knowledge, scientific understanding, and attitudes about ship-board limnological research (see D'Avanzo 2000, Langen and Welsh 2005).

3) Sharing the research platform with a research-oriented mission provides students the opportunity to see limnology applied to solving a task-oriented objective, as well as the opportunity to compare the skills they are acquiring with those used and needed by active limnologists.

4) The exposure of students to cutting-edge techniques advances the mission of the USEPA GLNPO to facilitate the development of the next generation of Great Lakes limnologists.

5) Our experience indicates that students will be highly motivated and engaged if there is an explicit expectation that research findings will be disseminated through conference presentations and publications that are student-authored.

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