

Models of Interdisciplinary Research and Service Learning at Hope College

Children love to explore the world around them. In doing so they are not aware of disciplinary boundaries or even of disciplines. They move freely from watching ants (biology) to building structures (engineering) to counting rocks (mathematics and geology) to seeing what things dissolve in water (chemistry). Only as they go to school do they learn that humans divide up the way we learn about the universe and start to think within disciplinary boundaries. In doing so, those children, who are now us, lose the ability to think broadly and use the insights of various ways of thinking to solve important problems. At Hope College, we are trying to return to our childhoods by supporting interdisciplinary research and teaching.

Our renewed focus on an interdisciplinary approach in the sciences at Hope began when the division was charged with developing courses for non-science majors following the adoption of a new general education program in 1996. In order to provide non-science majors with a broader experience in science, we began offering courses that included at least two disciplines, such as chemistry and geological sciences, and were developed by faculty members from two different departments within the division. The development of these courses was supported by an Undergraduate Science Education Program grant from the Howard Hughes Medical Institute (HHMI) in 1996. This grant also supported the development of some interdisciplinary research teams.

Because of the success of the interdisciplinary courses for non-science majors as well as the pilot program of interdisciplinary research grants and informed by the National Research Council report *BIO2010* (NRC, 2003; also see Barney and Bultman, 2006), we chose interdisciplinarity as the theme for a subsequent grant proposal to HHMI. In the meantime, Hope had remodeled and expanded one of its two science buildings in such a way as to encourage and facilitate interactions among departments. A significant component of our 2004-2008 HHMI Undergraduate Science Education Program award is the Faculty Development Grants for Interdisciplinary Research. To date, we have made 15 such grants involving faculty in 10 departments at Hope. The awards are for \$10,000 and the funds can be used for summer stipends, equipment, supplies, and travel. The primary goal of this program is to develop sustainable interdisciplinary science, technology, engineering, and mathematics (STEM) research



Hope College students Nathaniel Bowerman (left) and Paul Frybarger (right) work on the genome-scale metabolic reconstruction of microbial genomes in the bioinformatics research lab at Hope College.

teams involving faculty from at least two different departments at Hope. Additional expectations are that the awardees will involve undergraduates in the research work in a meaningful way, present and publish their work, seek funding from an external granting agency to continue the research, and integrate the research into courses in each of the disciplines represented. We have asked teams to make presentations to students, faculty, and administrators on campus so that the teams can serve as models of this interdisciplinary approach.

As we enter the fourth year of our HHMI grant, we are pleased with the progress we have made in returning to a childlike approach to understanding the universe. Interdisciplinary teams have involved undergraduate students in their research projects, made numerous presentations and published their work, obtained external funding, and helped transform our courses for STEM majors. These accomplishments have been made possible by the funds provided by the HHMI grant, the general collegial atmosphere that dominates Hope, support from the administration and faculty for interdisciplinary approaches, and students who have not moved as far from their childhood sense of exploration as have the faculty. To give a better sense of these accomplishments and the challenges that interdisciplinary research presents, we turn now to two specific examples of HHMI supported interdisciplinary research teams at Hope College.

Interdisciplinary Research Program in Bioinformatics and Microbial Genomics

Over the past three years, we have established an interdisciplinary research team at Hope College in the area of microbial genomics and bioinformatics comprised of faculty and undergraduate students from the Biology, Chemistry, Computer Science, and Mathematics departments. Our research program is founded within the growing field of systems biology, in which organisms are studied at the cellular level from the perspective of interactions among all components of the cell. This is made possible by the wealth of data derived from over 600 published genome sequencing projects (Liolios, Tavernarakis, Hugenholtz, Kyrpides, 2006; see Kyrpides, 2007) in conjunction with systems level data. Systems level data can be derived from microarray experiments that determine whether an organism's genes are on or off under differing environmental conditions, proteomics experiments in which an organism's total protein content is analyzed, and metabolomics experiments where individual chemical metabolites in an organism are measured under varying conditions. Our research group is focusing on developing processes for the automated generation of genome-scale metabolic reconstructions for all sequenced microbial genomes (DeJongh, *et al.*, 2007). The metabolic reconstructions serve as the starting point for computational modeling of microbial metabolism and offer a framework for interpreting and applying systems level data. Our repository of metabolic reconstructions serves as a resource for the scientific community to carry out metabolic modeling studies, which have a range of applications from bioremediation of toxic waste to exploration of strategies for producing alternative energy sources to virulence mechanisms of pathogens.

Four factors have contributed to the success of our interdisciplinary research program. First, there has been significant institutional support for fostering interdisciplinary collaborations among faculty. Second, both faculty and students in the program have been able to learn to communicate effectively across disciplinary boundaries. Third, the scope of the research program is sustainable at a liberal arts college. Fourth, we have used several important strategies to include undergraduate researchers in the program from its inception.

Institutional support and vision for fostering interdisciplinary collaboration among faculty have been instrumental in the success of our

Hope College students Kevin Formsma and Paul Boillot meet with Congressman Vernon J. Ehlers (representing Michigan's Third District) at the CUR Posters on the Hill conference held in Washington, D.C. in April of 2007.



research program. This began with the hiring process for faculty when each of us met with faculty from multiple departments (Computer Science and Biology). These meetings during interviews made it clear to us that a vision for interdisciplinary scholarship and learning was in place and being actively pursued. We have been the recipient of two of the HHMI seed grants, which have been foundational in providing summer stipends and supplies. Additionally, student researchers on this project have been funded through competitive awards from the HHMI program and National Science Foundation REU site awards.

A primary hurdle to effective interdisciplinary work is communication across disciplinary boundaries. As we began the process of devising research questions, we were forced to understand each other's skill sets and language. What expertise did each of us bring to the table? How did melding that expertise give us the ability to answer complex questions? In our case, this came together rather quickly as each of us had some background in the other's discipline. We engaged in concrete efforts to enhance understanding of background material; for instance, Dr. DeJongh audited a year long biochemistry course to better understand metabolism and biochemical conversions of molecules. Additionally, we held weekly meetings to discuss scientific literature; as we worked through these articles, we came to understand how the other thought about a particular problem.

Throughout this process, we have been intentional in providing opportunities for students working on the project to observe our interactions as well as work through complex problems with each other. We have developed a bioinformatics course that is cross-listed in the Biology, Chemistry, and Computer Science departments in which students gain a clear appreciation for the difficulties of communicating across boundaries. A survey conducted last year revealed that students began to understand the role of experts in an interdisciplinary setting:

It was very interesting communicating with the computer scientists. The experience was good. If anything you learn, I learned, that you have to step back and not try and understand everything because there is no way you can. You just have to know your part and what you are trying to accomplish.

I also learned a fair amount of biology. Mostly, however, it was just enough to get by.

As these comments reveal, in an interdisciplinary endeavor each participant must bring some expertise to the problem while at the same time have enough understanding of the other disciplines to “get by” or communicate effectively.

Another critical factor in shaping the focus of our research program is the setting of a liberal arts college. The demands on faculty time must be balanced among significant teaching loads during the academic year, active research programs that yield publications and external funding, and significant inclusion of undergraduate students in research. The field of systems biology and bioinformatics is a very fast moving area of science with major research institutions contributing significant resources of time, money, faculty and infrastructure to address complex problems through interdisciplinary teams. Competing for funding and answering important questions in this context is challenging. Our strategy has been to form a partnership with a team at a major research institution that is already developing highly sophisticated genome annotation and analysis software. In this process, we have identified genome-scale metabolic reconstruction and modeling as an area of investigation that is recognized as significant by our collaborators but is not being actively pursued. Thus, we have been able to carve out a niche where we can contribute functionality to a much larger research endeavor while maintaining enough independence to work at a pace suitable to our context. Another benefit of this arrangement is that our students are exposed to a broader context for research than we can provide at Hope College, giving them graduate school-like experiences as well as opportunities for external internships.

As mentioned above, we have been intentional about involving students in our research. Although the nature of the project narrows the pool of potential participants to those students who are willing to cross disciplinary boundaries, we have found that the students who are willing to take this step are generally highly motivated and productive contributors. The bioinformatics course that we have developed is designed to introduce students to the biological, biochemical, and computational concepts necessary to understand and participate in our research. Additionally, we have designed the course to produce student-conducted publication quality work that significantly advances the research program. In so doing, we have been able to use the considerable teaching responsibilities expected of faculty synergistically with scholarship. This approach has been extended to another course, Microbiology, where students undertake experimen-

tal validation of hypotheses derived from bioinformatics and genomics. To date, we have included over 20 students in course-based research activities. Students are also recruited from these courses to continue work on the project through independent research credit during the academic semesters and in full-time 10-week summer research programs and internships at Hope College and at collaborating institutions. This approach of incorporating undergraduates into all aspects of the project allows us to maintain momentum throughout the year.

Outcomes of our research program to date include a peer-reviewed publication with undergraduate co-authors (DeJongh, *et al.*, 2007), presentation of results at national conferences by faculty and students (*e.g.*, American Society for Microbiology General Scientific Meeting; Council for Undergraduate Research Posters on the Hill), and external funding of the project through the Argonne National Laboratory Guest Faculty Research Participation Program. These are the traditional metrics by which the success of programs is measured at Hope College and similar institutions that serve a primarily undergraduate student population.

Nursing and Engineering in International Development

Engineering and nursing students at Hope College are currently involved in an international development project seeking to improve the drinking water resources in a rural farming community of approximately 500 people in Cameroon, West Africa. The community of Nkuv is isolated, and basic water, sanitation, and electricity infrastructure is not developed. This project was adopted by the Hope College student chapter of Engineers Without Borders – USA in October 2005. It has developed into interdisciplinary research collaboration between engineering and nursing faculty. The collaboration began with a desire to move beyond a traditional service-learning project to a more challenging community development project incorporating public health assessment techniques from nursing to evaluate the short and long-term impacts that a clean water project, initiated by engineers, would have on the health of the community. Initial funding for materials and supplies was obtained from internally administered grants including an HHMI interdisciplinary research grant.

Issues related to international development provide an excellent opportunity for undergraduate students to engage in interdisciplinary research and learning. From the beginning, engineering students

Hope College engineering student Mark Humberstone samples water from a Manz Biosand Filter in Nkuv, Cameroon, West Africa.



Hope College engineering student Mark Humberstone discusses maintenance and performance issues related to Manz Biosand Filters in Nkuv, Cameroon, West Africa.

were forced to recognize that engineered systems rarely function in isolation and that social, cultural, and economic factors play an equally important role in the success or failure of a project. This project also gives nursing students the opportunity to explore the complexities and hard realities associated with access to health care and health education in remote underdeveloped areas. The objective is not to train engineers to be nurses or nurses to be engineers but to have students recognize when and how their own discipline becomes well informed as a result of interdisciplinary interaction. As faculty we strive to mentor students who can make decisions in the face of complexity and uncertainty using the scientific process, the resources at hand, and the expertise of their peers.

During the first phase of this project, engineering students focused on researching fundamental strategies for improving water quality in developing communities. Students formed two groups as part of their senior engineering design course in the spring semester of 2006. One group explored shallow wells and the other group explored techniques for treating existing surface water in the community. Nursing students planned for a village-wide community health assessment. The objective for the first 8 weeks of the spring semester was to prepare for a site assessment trip to Nkuv that occurred over spring break. This trip was foundational for a pilot implementation trip in May 2006.

The student work leading up to the site assessment trip involved limited interdisciplinary interaction. The engineering teams struggled with the challenge of designing a water treatment system based on little relevant data, and the nursing students were focused on the details of refining a community health assessment tool and planning for teaching basic health and hygiene cross-culturally. These were appropriate activities for each group at this stage in the process, but it was becoming clear that expecting interdisciplinary interaction before the students were confident within their own disciplines was unrealistic. Time constraints made structuring interdisciplinary meetings a challenge. It was hoped that traveling together for the site assessment would help to establish a link between the two groups and that the students would begin to value the insights of their colleagues. Ideally, all of the information gathered during this trip would be pooled together, analyzed collectively, and incorporated into the plans for the pilot implementation trip.

The site assessment trip proved productive for each of the groups. The shallow well team explored the hydrogeology in and around the community and identified locally available materials that could be used for a pilot well in May. The water treatment team performed a bacteriological analysis of the existing surface water and proposed several treatment system concepts to the community. The nursing students field-tested a health survey for children under five, and they spent time in and around people's homes discussing the priority intervention areas from the perspective of the community.



Hope College engineering student Mark Humberstone demonstrates the reduction in turbidity of water after passing through a Manz Biosand Filter in Nkuv, Cameroon, West Africa.



Hope College nursing student Heather Amundsen collects body mass index data in Nkuv, Cameroon, West Africa.



Hope College nursing student Katie Matre and engineering student Mark Humberstone perform bacteriological analysis of treated and untreated water in Nkuv, Cameroon, West Africa.



The Manz Biosand Filter shown in this photo was constructed by members of the community in Nkuv, Cameroon, West Africa, after receiving training from Hope College engineering and nursing students.

The spring break trip was followed by a pilot implementation trip in May 2006. At the conclusion of the May trip, it was still evident that our team was really comprised of three separate discipline specific teams engaging only superficially in interdisciplinary work. Each group was still developing and testing their area of expertise. Once the students were proficient in their discipline specific areas, we saw a shift in thinking and interaction among the students.

Between the May and December 2006 trips the engineering students started to teach the nursing students the theory and mechanics of the filters, while the nursing students were teaching the engineering students about public health, survey techniques, and the value of focus groups. This teaching and learning was facilitated when both groups of students were assigned tasks and responsibilities to complete together outside their areas of expertise. For example, we assigned one engineering and one nursing student to perform the microbiology testing on the filters both on campus and in the field. These two students started to see the value of interdisciplinary research and were soon working together to solve other more complex problems. As these students became the leaders on the next series of trips, we saw a trickle down effect and exciting interdisciplinary work that was student led.

Interdisciplinary thinking started with learning how to speak a common language at the faculty level. This is most evident in the progression of grants that were submitted. In the beginning our "interdisciplinary" grants had an engineering section and a nursing section tied together roughly. We struggled with measurable outcomes that both faculty

members could agree on. Now our grant proposals are integrated with a common language, measurable outcomes, and a community development framework.

Much of the transition from discipline specific to interdisciplinary took place outside the curriculum of both the nursing and engineering programs. At weekly team meetings, responsibilities for planning and coordinating the travel and research were discussed and interdisciplinary teams were given specific outcomes they were responsible for, but the teams had the freedom to decide together how they were going to meet those outcomes. At the team meetings, each group discussed the issues they were working on and solicited input from the rest of the team members thus encouraging students and faculty to think in new ways to solve real problems.

We may not have achieved the interdisciplinary goals we aspired to achieve during our first or even second field trip to Cameroon, but by the third and the fourth field trips the nursing and engineering students were seeing themselves as a team and seeking out the input from both disciplines when trying to solve complex problems.

The Cameroon Engineering – Nursing Research Team is now externally funded by the National Collegiate Inventors and Innovators Alliance (NCIIA) and getting ready to expand regionally. We have added education faculty and students to support the interdisciplinary model for the health education and community development aspects of the project. The village of Nkuv continues to welcome our team, and we look forward to several more years of partnership with them.

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