A Model for an Interdisciplinary Undergraduate Research Program

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In the May 2009 issue of *The American Statistician*, Brown and Kass (BK) offered thought-provoking answers to the question "What is Statistics?" which have direct implications for statistics education. For five years, St. Olaf College's Center for Interdisciplinary Research's (CIR) activities have aligned with BK in both philosophy and practice. We describe the program's motivation and design, how we recruit students and find faculty collaborators with suitable projects, and how the teams of faculty and students work together. A research skills seminar series parallels the research process and prepares students for working on teams. Inevitably, administrative issues arose which we identify and address. Landes (2009) identified significant issues related to recruiting. Our model of undergraduate education has proved to be fruitful on this front. Sending nearly 50 students to graduate school in five years from a college of fewer than 3000 speaks to the program's efficacy. Here we present a program based on authentic interdisciplinary research with undergraduates which embodies many of BK's ideas and addresses recruiting issues. Although this experience underscores the potential for new and exciting approaches to statistics education in the liberal arts environment, the model itself can be adapted by a variety of undergraduate programs. Supplemental materials are available online.

KEY WORDS: Collaboration; Graduate school; Mentoring; Nonstatistical skills.

1. INTRODUCTION AND OVERVIEW

In the May 2009 issue of *The American Statistician* (TAS), Brown and Kass (BK) (2009) offered thought-provoking answers to the question "What is Statistics?" which have direct implications for statistics education. For the past five years, St. Olaf College's *Center for Interdisciplinary Research* (CIR) has aligned with BK in both philosophy and practice. A large number of activities have taken place as part of the mentoring grant funded by NSF (grant 0354308), but as the program evolved it has been the Center for Interdisciplinary Research that has become the focal point. The St. Olaf CIR exposes undergraduate students to what statisticians really do. In many ways, it is similar to models of undergraduate research in the laboratory sciences. Students learn about statistics by doing statistics in authentic collaborations with researchers from other disciplines such as biology, economics, linguistics, psychology, chemistry, and political science. They work in *Interdisciplinary Research Teams* consisting of three to four undergraduate statistics students and two faculty members: a "domain expert" from another discipline and a statistician serving as a mentor to the students. The research projects the teams tackle are both in-depth and long-term, extending through an entire academic year and occasionally into the following summer.

Students are guided in their research throughout the year by attending a *Research Skills Seminar Series* that complements the activities of the research process. The focus of the series is communication skills—communicating with researchers from other disciplines, communicating through technical and nontechnical talks, communicating via posters and scientific papers. The series also provides information and inspiration about statistical careers with visits from practicing statisticians and graduate students among others. In addition, weekly evening meals preceding the seminars have been an unexpected source of community building among the statistics students.

The purpose of this article is to describe an example of a program based on authentic interdisciplinary research with undergraduates which embodies many of BK's ideas and addresses the issue of recruiting. We maintain that the CIR is not an isolated, anomalous effort. We contend that such a program, in various forms, is possible at many undergraduate institutions. It is our hope that CIR provides some inspiration for others. Toward that end, we describe the motivation and design of St. Olaf's CIR along with lessons we have learned and practical guidance based on our experience. However, we begin at the end—by describing the impact of the CIR at St. Olaf College, with special emphasis on the program's success at contributing to the graduate school pipeline.

2. IMPACT OF CIR

Over its five-year grant period (2004–2009), the CIR has had significant impact on what our students study as undergradu-

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ates, the kind of work they produce while in school, and what they do after graduating. It has also invigorated interdisciplinary research on campus. It is fair to say that the observed impact has far exceeded our expectations.

2.1 Student Research

An immediate effect of CIR is the change in what our students produce as undergraduates. From the 2004–2005 academic year to 2008–2009, the 116 students (several students participated more than one year and are double counted in this total) who made up CIR teams worked on 42 projects, producing and presenting one or more posters for each project. Each team formally presents their results in oral and written form to their collaborators and to the St. Olaf community through the annual St. Olaf Science Symposium. In addition, students have presented their work in a variety of external venues including the National Conference on Undergraduate Research, Posters on the (Capitol) Hill, and Expert Panels at the World Health Organization.

2.2 Postgraduation Plans

Among many others, Landes (2009) identified the recruitment of students into the statistics profession as a priority. During the five-year NSF grant period (2005–2009), 102 students earned statistics concentrations compared to 69 a decade earlier (1995–1999). More impressively, 47 went on to statistics or epidemiology graduate programs from the classes of 2005–2009 while we could identify only 5 to possibly 7 students who went to graduate school in statistics in the five-year period a decade earlier.

Rather than go directly to graduate school, a number of students choose to seek employment as statistical analysts at places like the Mayo Clinic and the U.S. Census Bureau upon graduating. Others take time out after receiving prestigious awards such as a Rhodes Scholarship or a Fulbright Scholarship, some with intentions to go to graduate school at a later date. The CIR program has also been popular with pre-med students, and we are happy to send such statistically literate students to medical schools.

2.3 Campus Research Community

CIR activities have invigorated research all over campus. Students along with their statistics mentors provide a service to the campus community by enriching faculty research with appropriate statistical methods. Regular weekly meetings help researchers continue to make progress during the busy academic year.

The CIR has even changed the physical landscape, albeit in a modest way. A room dedicated to the CIR was included in the new science building at St. Olaf, conveniently and symbolically located in the link between the natural sciences and the mathematical sciences. This room is open to CIR students and their collaborators during the day and evening. It serves as a recruiting tool of sorts for students who might consider a statistics concentration, and it serves as a reminder to faculty that there are resources for them when planning a study and analyzing data. Although modest in its impact, it underscores the importance of keeping visible to potential new students, and it is a manifestation of the college's support.

2.4 The Statistics Curriculum

The CIR has had a significant impact on our statistics curriculum. The development of the CIR has coincided with radical changes in our statistics concentration. The statistics courses in our former concentration were probability, mathematical statistics, and linear models in that order. The overhauled concentration now affords students the opportunity for a full year of applied courses—Statistical Modeling [multiple linear and logistic regression at the level of *The Statistical Sleuth* by Ramsay and Schafer (1997)] and Advanced Statistical Modeling (generalized linear models and correlated data methods)—without requiring probability and statistical theory. Following Statistical Modeling, students may choose to study probability and statistical theory. Alternatively, students who are not mathematics majors may choose from discipline-specific methods courses such as psychology methods, design of experiments, or biostatistics in Geneva. As BK recommended, students are now poised to begin applied research earlier in their career and are welcomed even if they come from disciplines other than math and do not intend to take probability and statistical theory. We have found this to be an effective approach and have had a number of "non-math" majors declare an interest in statistics and begin taking mathematics courses to prepare for graduate school.

More than a reordering of courses is taking place. The content of the curriculum is changing, particularly in the Statistical Theory and the recently created Advanced Statistical Modeling courses. Statistical modeling is now required prior to taking Statistical Theory. (Statistical Theory also requires probability theory.) After exposure to statistical thinking and real data in Statistical Modeling, students in Statistical Theory now have an applied context in which to place the theoretical ideas they study. With the applied context, students in statistical theory can tackle much more than the traditional set of topics covered in mathematical statistics. Having delved into applied research, they can see the value of 'new' statistical theory topics such as MCMC and bootstrapping. According to BK, "...courses tend to be categorized as either theoretically oriented for math/statistics majors or methods oriented 'service courses' for other disciplines." Curiously, while a "theoretical" course like Statistical Theory addresses practical tools such as bootstrapping and MCMC, our "applied" courses introduce students to notions such as likelihood and exponential families.

An advantage of the former course sequence (Probability, Math Stat, Linear Models) is its ready appeal to some mathematics majors, but the sequence proved to be intimidating to many interested nonmath majors and too obscure for those math majors drawn to application. A danger of starting students in applied courses is the potential lack of appeal to math majors. The "applied" courses in our curriculum now include accessible theoretical concepts helping us to represent "the discipline as being rich in profound concepts" as BK suggested. We have not strived to offer courses to cover every possible method CIR students may encounter. Rather, students start with a foundation in regression and then learn "just in time" statistical methods needed for their projects. As BK suggested, once we understood our "...primary mission as helping students develop an ability to think like statisticians, [we were] freed from the constraints of excessive content—flexibility is paramount." Our course content now more accurately reflects what we believe to be the important features of the undergraduate experience in statistics.

3. CIR MOTIVATION AND DESIGN

3.1 Pipeline: A National Need

Landes (2009) (see BK for appropriate form) called for improved action tailored to recruiting students to the profession; mentoring undergraduates in the field of statistics with the aim of encouraging them to attend graduate school in statistics has been the overarching goal of our program. A motivation for the CIR program ultimately stemmed from the "unprecedented demand for statisticians—a demand that has gone largely unmet" (Dixon and Legler 2003). An NSF report (2003) ranked filling the pipeline with students for graduate study in statistics as a top priority to address the critical shortages of statisticians in science, medicine, industry, government, and academia. The St. Olaf College program provides a model for ways in which undergraduate statistics programs can help to fill the pipeline by addressing two critical transition points in the career paths of statisticians—deciding to study statistics and deciding to pursue graduate study.

The design of the CIR program was also motivated by newly emerging issues for educating undergraduates in statistics. At its foundation, the CIR incorporates interdisciplinary inquiry-based learning with explicit attention to nonmathematical skills. Each of these crucial program tenets will be described more fully below.

3.2 Experientiality

In 2006, the PKAL Report on Reports II (Project Kaleidoscope 2006) recommended that each undergraduate be afforded the opportunity for "personal experience with inquiry-based learning that brings him or her to a deep understanding of the nature of science, the language of mathematics, the tools of technology." They went on to suggest that these research opportunities take place outside the classroom and even off-campus. Their recommendations for producing well-prepared graduates included establishing collaborations of academe, business, and civic groups. The Center for Interdisciplinary Research (CIR) was conceived as an experiential component focusing on in-depth inquiry outside the classroom.

3.3 Interdisciplinarity

Why not create an experiential program solely within the statistics program? Why have it be interdisciplinary? There are at least two compelling reasons. First, there has been national recognition of the value of research involving two or more disciplines. One example of this commitment to interdisciplinary learning can be found in the *Futures Initiative* by the National Academies and the Keck Foundation in May 2003. The purpose of the program was to tap the full potential of interdisciplinary research. "Training individuals who are conversant in ideas and languages of other fields is central to the continued march of scientific progress..." (National Academies and Keck 2003, *http://www.keckfutures.org/*). Again in 2004, a National Academies publication made a strong case for training workers with interdisciplinary experience who work well in a team setting. In their article, BK made a specific recommendation to "Encourage deep cross-disciplinary knowledge."

The second compelling reason for an interdisciplinary program is the changing practice of statistics. There was a time when statisticians spent very little time with researchers from other disciplines except to "consult" on sample size or obtaining a p-value. BK recognized the shortcomings of this perspective for modern educators: "Statistics departments often act as if they are preparing short term consultants—able to answer circumscribed methodological questions based on limited contemplation of context. This short term model relegates the statistician to a subsidiary position." Now it is much more common to find a statistician participating as part of a team of scientists, as a collaborator. BK suggested that "...in today's dynamic and interdisciplinary world, success in confronting new analytical issues requires both substantial knowledge of a scientific or technological area and highly flexible problem-solving strategies." We agree that "the discipline of statistics needs to recognize our new situation and act accordingly." Thus, participation in CIR requires that students (and faculty) be willing to work hard to learn about another discipline in order to be an effective contributor.

3.4 USEI Guidelines

The changing practice of statistics has numerous implications for statistics education. Many of these recommendations are spelled out in the American Statistical Association (ASA)'s Undergraduate Statistics Education Initiative (USEI), which provided much of the scaffolding for the design of the CIR. Many readers of TAS know that the American Statistical Association convened experts from academia, government, and industry to make recommendations for training today's statisticians at the turn of the Millennium. These experts proposed the Undergraduate Statistics Education Initiative which was eventually sponsored by the ASA as Curriculum Guidelines for Undergraduate Programs in Statistical Science. The USEI recommendations appear in the works by Bryce (2002), Bryce et al. (2001), and Tarpey et al. (2002). The guidelines set forth five sets of skills:

1. Statistical skills
2. Mathematical skills
3. Nonmathematical skills
4. Computing skills
5. Substantive area skills.

The CIR facilitates skill building in all five of these areas.

Statistical Skills

CIR students often explore statistical methods appropriate for their data, even if they have not been exposed to the methods in a formal classroom setting. Examples have included Bayesian inference for phylogenetic trees, random forests, ordinal regression, and Mantel tests for distance matrices.

Mathematical Skills

As BK stated, "...students who want to solve real problems will be attracted to cross-disciplinary research" of the type that occurs in the CIR. Inspired by solving real problems, many CIR students have been motivated to increase their mathematical skill set to better understand statistical methods they may use, including math majors who proceed to take courses like statistical theory and real analysis, and nonmath majors who take courses ranging from linear algebra to probability theory.

Nonmathematical Skills

The authors (Bryce 2002) note that "Non-mathematics based statistical skills are *currently the ones most likely to be neglected* in a statistician's education." Components of the CIR, especially the weekly research skills seminar series, are designed to explicitly develop nonmathematical skills, including the ability to write clearly, speak well, and use appropriate media in presentations. Such communications should include delivery to large or small audiences, both technical and nontechnical in nature. Teamwork is another nonmathematical skill and is also an integral part of what a statistician does. According to the USEI, "opportunities to practice these skills should be included in a variety of venues in an undergraduate program."

Computing Skills

"In practice the statistician is also called upon to manage data collection processes. This requires skill at organizing and managing projects and understanding how problems are formulated...." Among those who were a part of USEI, there was unanimous agreement on the need for the undergraduate statistics curriculum to include a heavy emphasis on data analysis. Depending upon the project and mentor, students will be using Stata or R extensively. This emphasis reflects modern statistical practice, and also helps position students for careers either in industry or graduate school. They should have experience with "messy" data and with cleaning and downloading data; every CIR project provides such an opportunity. BK echoed these sentiments, stating that training statisticians requires "analysis of procedures for data collection, prediction, and scientific inference."

Substantive Area Skills

Every research team begins with a thorough literature review of the subject area for their research question because an effective statistics collaborator must understand the science behind the data they are analyzing. Successful research teams have often included students who have majors in the field of the domain expert.

Participation in the CIR requires skills from every one of the areas mentioned in the USEI. In the past, training statisticians focused on statistical and mathematical skills. Now adding emphasis on nonmathematical and substantive area skills prepares students in the very skills needed for interdisciplinary research.

4. ACTIVITIES/COMPONENTS OF CIR

4.1 Recruiting and Selecting Students

At St. Olaf, we invite eligible students to apply to be CIR Fellows. Eligible students must have an exemplary academic record and good recommendations from other faculty. It is critical that students accepting the fellowship be hard working, reliable, and capable of working together in groups.

Applicants are required to have successfully completed an applied regression course (at St. Olaf, the text used for this course is *Statistical Sleuth* by Ramsey and Schafer). This low minimum course requirement has worked well for us. Even with no additional courses in the curriculum, students have been able to learn about new methods such as classification trees or survival analysis in their research teams. Repeated group presentations to one another also disseminate an awareness of other methods; not all groups will develop the same set of expertise, and not having certain upper-level courses need not be a deficiency. Our approach is consistent with BK's recommendation that the "...prerequisites to research" be minimized.

Another appealing argument made by BK that we have taken to heart is the idea that we "...broaden the notion of what a statistician is." BK asked: should students "without calculus and strong scientific backgrounds" be considered prime candidates for earning statistics degrees? In the past we sought statistics concentrators mostly from among mathematics majors. While the pool of mathematics majors remains a good source of statistics concentrators, we now look for strong students in any of the natural or social sciences. There are times when CIR students have an excellent preparation in science but have not yet pursued extensive training in mathematics. Our experience has been if these students develop a strong interest in the field of statistics while in CIR they are more than willing to pick up the essential mathematics. While BK argued for this approach at the graduate level, it is worthwhile considering this approach at the undergraduate level where students are more likely to find the time and support to succeed in the mathematics courses.

Students' attitudes play a critical role in a collaboration and should be kept in mind when selecting fellows. Statistics faculty model interactions with collaborators for the students initially, but eventually students assume the primary statistical role in the collaboration. This requires that students be respectful, articulate, patient, humble, and good listeners.

We are not shy (this was especially true during the formative years of the CIR) about promoting the CIR to targeted students and recruiting specific students. Statistics faculty promote the CIR both in introductory courses to encourage students to keep taking statistics and in core courses to encourage students to apply. We also approach promising students individually to let them know about opportunities in statistics at St. Olaf and beyond. In addition, we have two evenings of CIR presentations to introductory statistics students (who were offered extra credit for attending) each semester which serve very effective dual purposes—the introductory students learn what the CIR is all about from their peers in the program, while the CIR students get practice giving oral presentations to a nontechnical audience, describing their research project and the statistical methods they plan to employ.

In the early years of CIR, we tried to accommodate as many students as possible, including some who were marginally qualified. St. Olaf Mathematics is known for its "Big Tent" philosophy, and it is a philosophy that we in statistics take to heart. This philosophy produced a few surprising success stories, but also a few problems with students not carrying their weight in their groups. We now set an upper limit on the number of students (usually 3 times the number of projects) and make tough choices where necessary, although we maintain enough flexibility to accommodate borderline students with potential for statistics beyond St. Olaf.

4.2 Recruiting and Selecting Projects and Collaborators

4.2.1 Collaborators

Like many undergraduate colleges, we discovered that many St. Olaf faculty members are performing research that could be enhanced by statistical expertise. When we started seeking out potential research projects and collaborators at the beginning of the CIR, we were surprised at the number and variety of viable research projects which existed. Many nonmathematics departments in undergraduate institutions are hiring new faculty with research which makes use of quantitative methods. It is our belief that this is not unique to St. Olaf; we are confident that most undergraduate institutions across the country also have a rich source of research problems that are accessible to undergraduate statistics students.

In the spring we approach faculty from other disciplines to solicit problems for the following CIR year. We have found faculty members are willing and even eager to describe their research over a cup of coffee or a face-to-face visit to their office. During this conversation, we describe the CIR structure to our colleague, and most are very interested in becoming involved with the CIR upon learning that, at no cost to them other than an hour or so per week, they will have three capable statistics students, mentored by a statistics faculty member, working exclusively on their project over the academic year. Despite the relatively low minimum time commitment, it is nevertheless important to gauge a potential collaborator's interest level and ability to maintain consistent engagement. In order for us to continue to consider their research for a CIR project, we ask that each potential collaborator write a paragraph to describe his or her research and assemble a list of important background papers. Faculty who are unable to take the time to fulfill this modest request are usually no longer considered.

Although the majority of our collaborators are faculty colleagues, we have had very good luck with administrative staff as well. We have gotten excellent projects and found good mentors in the admissions, financial aid, advancement, and evaluation and assessment offices.

We make a concerted effort to have a large proportion of CIR projects originate from internal (St. Olaf) sources. Not only do St. Olaf colleagues provide a rich and deep source of potential projects, but we believe that reaching out to and working side-by-side with colleagues from other departments and offices helps create an interdisciplinary culture on campus and increases the visibility of the statistics program to students and faculty alike.

Of course, we have periodically undertaken projects from external sources, primarily based on contacts of the statistics faculty with researchers at other schools or organizations such as the World Health Organization. We have even organized projects around data our students had collected while working with nonprofit organizations during the summer (e.g., health care in rural Guatemala). A greater proportion of external projects tend to be run during the summer, but the primary emphasis of this article is on academic-year research programs. Most of these projects from external sources have worked smoothly; the few challenging projects we experienced tended to be the result of collaborators who were less committed or accessible, or when the nature of a project was more conducive to face-to-face interactions.

When inviting collaborators, we aim for a diverse set of research—different disciplines and various statistical methods. For instance, we have worked with Exercise Science, Education, and Political Science, and we anticipate projects in literature, music, and religion based on conversations with potential collaborators. This diversity enriches the statistics faculty experience and also that of the CIR students, who will hear about other groups' research throughout the year. The intent is to illustrate to the students that statisticians can work in a wide variety of areas. Because we always collect more potential problems than our teams can handle, the students are able to identify problems that interest them and statistics faculty can form teams based in part on statistical methods they would like to explore.

Characteristics of good collaborators include organization, reliability, and dedication to their research and students. They must be generous with their time, gracious about any findings, and, maybe above all, exude intellectual enthusiasm. Collaborators' passion and enthusiasm is contagious to both CIR students and faculty mentors. An unsolved research problem that a collaborator is passionate about can generate genuine suspense that a straightforward textbook problem cannot. What will we find? The collaborators' investment also provides a powerful source of motivation for students—it is not the statistics professor cracking the whip but rather a commitment to the collaborator that drives the students.

Dr. Rika Ito, a linguist at St. Olaf, is an example of an enthusiastic collaborator. At our very first meeting, the entire team—students and statistics faculty alike—learned a lot about the field of linguistics. Dr. Ito described the importance of linguistics in dramatic terms, impressing us all with the way in which linguistics could tell us about our changing society and how people's lives are affected by their patterns of speech. She described the painstaking effort that goes into collecting linguistics data, as well as the critical questions she hoped to answer with the data. As the project progressed, CIR students would eventually find themselves explaining the statistical methods they were using to address these questions. In this case, CIR teams worked on research problems Dr. Ito brought to us for three years.

4.2.2 Research Projects

Our requirements for projects are simple. The project must be a real-life, unsolved problem of interest to the researcher and his/her colleagues. This is in line with BK's recommendations that training statisticians involve "real-world problem solving," and that "project courses *especially at the undergraduate level* can be helpful" [emphasis the authors']. The research project itself must be rich enough to provide a year's worth of work by three or four students. It should be an unsolved, but solvable problem (at least in pieces). Problems are typically complex, often requiring a large amount of disciplinary background knowledge. The data are often messy, and at the start the questions may not be well-posed. Time is explicitly designated in the CIR schedule to learn about the subject area and manage the data.

It is incumbent upon the statistics faculty to ascertain whether a problem is viable or not. It should involve data that can be cleaned in a reasonable amount of time. It should have some depth but not be so complex that it cannot be tackled in an academic year. Most real projects provide a good experience, even if many of the statistical methods used are from an introductory course. Student researchers should always be encouraged to investigate basic descriptive statistics with their data. Sometimes that is all the domain expert needs. There is almost always a chance to investigate more complex statistical methods once the researcher's questions have been answered. A good project will often have several possible stages/levels to complete, so success can be achieved even without doing "everything on the list." For briefer research questions, CIR fellows hold weekly office hours available to faculty, staff, and students doing independent research projects. The CIR Team Project provides depth and the office hours provide breadth.

Although less typical, we have started projects where data collection is planned but no data are in hand. These projects can work fine (and actually allow students input into data collection planning) as long as there is reasonable confidence that the students will have sufficient time to analyze the data. For example, we recently developed a successful partnership with one group of three CIR students and an upper-level research methods class in sociology. The class consisted of a large data collection and analysis project designed to investigate open sociological research questions with a campus survey. The CIR students were each assigned to research groups within the class and collaborated with them throughout the process of forming research questions, designing a survey, collecting the data, organizing and analyzing the data, and presenting final results.

While it is desirable to obtain some results by the end of the academic year, it is okay to have work remaining. If other research questions arise during the course of the year or if certain analytical approaches remain unexplored, a team may continue its work into the summer. Seeing how research generates as many questions as it answers is a valuable lesson.

The nature of real research introduces the danger of a team not finding anything 'significant.' While statisticians find this to be a natural part of the scientific process and not a major concern, it seems as if most of the examples in the students' texts discover some statistically significant relationship. No significant results, however, can be a teachable moment, introducing students to real-life research.

A list of project descriptions from past years is included among the supplemental materials online.

4.3 Research Team Activities

A typical overview of research team activities over the course of an academic year follows. We will discuss each phase in more detail below:

- September: teams form; opening banquet
- September–October: literature review; data cleaning; interpersonal communication
- November: research plans talk; submit abstract
- November–March: data analysis; investigate new methods
- April: poster presentations
- May: write manuscript; finalize research log; end-of-year party.

September: Teams Form; Opening Banquet

In many settings, statisticians work in diverse teams with colleagues from other disciplines. This team-based model was adopted for the CIR not only to provide students exposure to the way in which so many statisticians work today but to also provide collegial assistance and support to one another. While most projects are not overwhelming, nearly all of them require "many hands" for data collection or management, for subject area expertise, for statistical analyses, and for communicating results in talks, posters, and scientific papers.

In our experience, two is the minimum for a team and five has felt like too many. In general, three seems to be the ideal number for balancing student engagement, having sufficient peer support to get the work done, and efficiently using faculty time. In fact, one of the secondary motivations for setting up a structured program like the CIR is to allow faculty to mentor more students more thoroughly than one could as an advisor to individual research projects.

Student teams work during the academic year, usually meeting weekly with both the statistics mentor and the collaborating researcher. Teams also meet on their own to discuss ideas, perform analyses, and plan ahead. Some research also takes place during the summer, for which students and faculty receive a stipend, but this article focuses on our academic-year undergraduate research program.

A compelling motivation for students is that they have an obligation to the collaborator and statistics program. They must have things done on time, assure accuracy, and use appropriate methodology. To make sure that these obligations are understood by students, it is necessary to explicitly address this with students at the outset and throughout the year. We lay out complete expectations for CIR Fellows at an Opening Banquet attended by all students, statistics faculty, and domain expert collaborators.

September–October: Literature Review; Data Cleaning; Interpersonal Communication

BK's concern that statistician training focuses on being "...able to answer circumscribed methodological questions based on limited contemplation of context... relegat[ing] the statistician to a subsidiary position" struck a chord with us. We heartily agree that "A statistician will have more impact generating ideas for scientific investigations if they understand the context" (BK). We are adamant that research team members learn as much as they can about the research area subject at the outset. It is our belief, and our experience as collaborators in a number of different settings, that acquiring in-depth subject area knowledge as it relates to the research question at hand distinguishes statisticians as real collaborators and in no way subsidiary. Domain experts pass along references which provide subject area background and potentially show other analytical approaches taken by other researchers.

Early on, we focus heavily on developing interpersonal communication skills that will allow students to function well in a team environment and communicate well with their collaborators. Statisticians must be able to offer careful, straightforward explanations to collaborators. Students can easily fall into using jargon, partially because of a lack of confidence in their understanding and partially because of an inability to gauge the understanding of their collaborators. This awareness of potential communication issues and knowing how to handle them aligns nicely with the USEI guidelines promoting nonmathematical skills.

Teaching students to run efficient and productive meetings takes time at the beginning of the year. We have found it essential to specify deliverables for each team meeting and begin each meeting discussing and evaluating the deliverables. Initially, the statistics mentor can model interactions between the collaborator and the team, but the students should eventually assume more responsibility. In the case of conference calls (or even face-to-face meetings), it can be a little nerve-wracking for students to speak on a call with so many people listening. It may be helpful to have each student select a topic and have a report and/or questions ready on that topic. In addition, the designated student should be very familiar with any results sent to collaborators prior to the call and be able to explain how they were obtained and what they might imply. It would be a good idea to go over each student's material in some detail before a call—at least before the first few calls.

It is important students understand the value of being sensitive and responsive to collaborator concerns. The questions the analyses address should be driven by the collaborator. There is a real danger of answering the wrong question if the statistician does not listen carefully to the collaborator. On the flip side, sometimes the experiment, study, or the data do not really allow the research question of interest to be addressed directly. It is important before going too far for the collaborator to understand what kind of conclusions can be drawn when the analysis is complete. It is often helpful for faculty mentors to meet without the students every week or every other week to sort out issues related to analyses or work-related issues.

November: Research Plans Talk; Submit Abstract

Early in the process, research teams should be able to articulate the research questions they hope to answer and conclusion statements they hope to be able to make by the end of the study. In this way, the important questions can guide the entire research process. To reinforce this orientation, each research group presents a research plan talk to a group of introductory statistics students, complete with background information and planned statistical approaches. In addition, each group writes and hopefully submits an abstract containing anticipated conclusions, paving the way for possible presentation of their results in the spring.

November–March: Data Analysis; Investigate New Methods

Each group begins with exploratory graphics and summary statistics; often they must be reminded not to skip this important step and jump into the latest complex model they just saw in class. In fact, we now make an effort to reinforce the importance of beginning with simple descriptive statistics when beginning an analysis. If it becomes clear that the important research questions cannot be adequately answered with methods known to the students, they begin to learn new methodologies with guidance from the statistics mentor.

As time progresses, you will (or should) witness a buy-in, that is, commitment on the part of the students. Students become the owners of the analysis. They begin to see that the results of the analysis are very important to the collaborator, who may have publications or even tenure depending on the results. They realize that their CIR work is much more than a class assignment, which implies more responsibility but also makes it more rewarding. A favorite (yet typical) quote from a CIR Fellow following a presentation to domain experts at the end of the term was: "They were so interested in our results."

April: Poster Presentations

Nothing provides motivation like a deadline, especially one involving a public display of your work. With that in mind, we require every CIR group, at a minimum, to present their work in a poster at the annual St. Olaf Science Symposium. Many groups will, in fact, also present their work externally at venues such as the National Conference on Undergraduate Research, Posters on the Hill, and the Pew Midstates Consortium for Math and Science. CIR students have also presented at regional and national discipline-specific conferences in Des Moines, Seattle, and Detroit, and at invited workshops at the World Health Organization in Geneva.

Frequent and (reasonably) firm deadlines are absolutely necessary. Students greatly underestimate the number of drafts and extent of edits it takes to get a poster or paper ready for public presentation. They also underestimate the number of dry runs (with constructive feedback) it takes to produce a quality oral presentation.

May: Write Manuscript; Finalize Research Log; End-of-Year Party

At the end of the year, each group is required to submit to their collaborator a draft manuscript and a research log. The research log should detail the group's activity on a weekly basis, summarize key decisions and analysis steps, and provide a guide to any electronic files. A thorough research log is essential for anybody (the collaborator or future students) who desires to pick up the research where the CIR team left off. The manuscript is written in scientific paper format, but due to time constraints, it is rarely polished enough for immediate submission. But it provides the domain expert with a coherent summary and a starting point for any future paper.

Two issues related to publication of CIR research are worth noting. First, it is very difficult to complete a paper with undergraduates who seem to graduate much faster than their graduate school counterparts. With this in mind, we have proposed a Summer Writing Fellows pilot program, in which worthy groups would receive summer funding to spend time writing up their CIR work into a submission-ready manuscript. The second challenge is authorship. When the research emanates from another discipline, there is sometimes a reluctance to include and acknowledge CIR fellows on posters and papers. This issue is best handled with early, private discussions between the statistics mentor and the domain expert.

Finally, the end-of-year party may seem superfluous or extravagant, but we have found that a vitally important element to the long-term success of the CIR is creating a sense of community among the statistics students. Thus, we try to build in several events which celebrate and embrace being together. The end-of-the-year party allows us to acknowledge the hard work of all the students throughout the year, and to enjoy each other's company is a decidedly nonacademic setting.

4.4 Weekly Seminar Series

Students attend a weekly research skills seminar series where they learn, among other things, supportive skills to facilitate their success in research. Not surprisingly, communication skills rank high on the agenda. As the USEI Guidelines acknowledge, the proliferation of team-based working environments in graduate school and beyond calls for increasing emphasis on communication skills: written, oral, and interpersonal. In fact, the topics of our roughly 25 meetings over the course of the year could be broken down as:

- interpersonal communication (5)
- oral presentations (5)
- poster presentations (4)
- manuscript preparation (4)
- graduate school and statistics careers (3)
- ethics (1)
- miscellaneous (3).

In each seminar meeting, our philosophy is to engage the CIR students in active learning which builds and reinforces skills appropriate for the current stage of their projects. Secondarily, we hope to use the seminar meetings to build a sense of community among the CIR fellows and to promote statistics as an exciting and advantageous choice for careers and graduate school. A complete syllabus from our most recent year-long seminar series is provided in the supplemental materials online; this section offers highlights from each of the topic areas listed above.

Interpersonal Communication

Early in fall semester, as the CIR groups are getting up and running, we assign readings (Boroto, Zahn, and Short 2000; Derr 2000; Spurrier 2000) to get students thinking about effective consulting and effective consulting sessions. Then we get students to put ideas into practice through mock consulting sessions. During these mock consulting sessions, students must work with a guest researcher (often a statistics faculty member role-playing a challenging client) to extract research questions, learn about the subject area and relevant data, and later explain statistical methods. The mock consulting sessions work best when students get a mock email beforehand describing in a few paragraphs the purpose of the meeting. The students quickly realize what sounded so easy and common-sense in their readings can be quite challenging to implement in reality without practice and focus. After these mock consulting sessions and a few meetings with their CIR project group, we often bring in a practicing statistical consultant from a company in Minneapolis or St. Paul to offer insight and practical advice.

During spring semester, in an effort to give students more experience with considering statistical approaches to different problems, we designed two sessions called "Case Studies in Statistical Consulting." In the first session, students read short scenarios associated with small datasets from *Problem Solving: A Statistician's Guide* by Chatfield (1995) and discuss in small groups how to approach each problem. The moral of most stories is that thoughtful graphics and summary statistics can often be all that is necessary. We have found that our students need a strong reminder like this as they begin their data analysis in earnest, since their tendency is to dive straight into the deep end of complex and sophisticated analyses. In the second session, students examine draft posters prepared by other St. Olaf students (for instance, student groups from a sociological research methods class) and are asked to comment on the graphs shown, the summary statistics displayed, and the statistical analyses employed. Once again, most methods required are fairly basic, but the CIR students get practice connecting research questions to data displays and analysis.

Oral Presentations

During fall semester, each research group presents a research plans talk to a group of introductory statistics students, complete with background information and planned statistical approaches. Giving a research plans talk early forces the research groups to master the background literature, enunciate research questions, and consider potential statistical approaches. Not by happenstance, the introductory statistics students who attend these talks consistently emerge intrigued about both the field of statistics and the CIR; these talks are an excellent recruiting tool!

During spring semester, each research group presents a "technical talk to a non-technical audience." Their charge is to explain a new statistical concept to an audience of introductory statistics students; the concept should be one the CIR students are using in their research project so that it can be discussed in the context of the problem. Once again, these talks serve as excellent practice for our CIR students and a recruiting tool for future CIR students. However, some recent talks have produced mixed results—students sometimes tackle too much or lack confidence to expound on complex methods. Mentor input and frequent practice are both crucial to helping the students produce a good talk.

We intend to take greater advantage of videotape in the future, both for the mock consulting sessions and the oral presentations. Sometimes that detail (setting up video equipment) gets lost in the shuffle, but in the process we lose out on teachable moments.

Poster Presentations

All research groups are required to create a scientific poster to present internally at the St. Olaf Science Symposium; many students also present their work at local and national conferences. Students read about characteristics of good posters and even create their own scoring rubric which we use to score posters hanging throughout our science building. Through multiple drafts, peer review, and mentor input, we emphasize both a quality poster and students' ability to orally present the results in the poster.

Manuscript Preparation

Each research group is expected to produce a draft scientific manuscript to deliver to their collaborator by the end of spring semester. During fall semester, we "warm-up" to writing by requiring each group to write an abstract, which many groups will submit to a conference of interest. Toward the end of spring semester, students write their manuscript in pieces—first the introduction and methods, and later the results and discussion sections. All manuscripts are subject to extensive peer review, where student reviewers apply standards we have read about (Spurrier 2000), which focuses their efforts at three levels: global issues (themes, etc.), paragraph issues (structure and clarity), and sentence/word issues (transitions, word choice, spelling, and grammar).

Students can feel swamped at the end of spring semester, when they are trying to finish analyses, write posters and papers, and keep up with their other classes. Spreading deadlines out (e.g., writing the introduction and methods early) is very helpful. In addition, we are considering a Summer Writing Program to allow students with potentially publishable work to refine their manuscripts while things are still fresh.

Graduate School and Statistics Careers

Select evenings of the seminar were used to expose students to careers in statistics through visiting statisticians and grad school panels. These are quite effective and reinforce BK's recommendation that "Training programs at every level should include many opportunities for trainees to interact with experienced statisticians." In fact, we have had good luck with invitations to statisticians from academics, industry, and government—they often give both a general department seminar and then a more informal discussion with the CIR fellows. Also inspiring was the return of CIR alumni who currently are in graduate school. Without any coaching from us, these graduate students provided convincing testimonials to the current fellows about the value of CIR. We have also received similar messages through emails. These unsolicited missives are both compelling for the current students and gratifying for the statistics mentors.

Ethics

Each year we devote at least one session exclusively to a discussion of ethics. Students read documents such as the ASA Ethical Guidelines, St. Olaf's Code of Ethics for Projects with Human Subjects, and the Belmont Report. We discuss these guidelines, and then ask small groups of students to consider ethical case studies based on the authors' experiences. Some years we have been fortunate to have guest speakers talk about ethics from their personal perspective. For instance, David Banks gave one particularly memorable presentation placing statistical ethics in a historical context.

Miscellaneous

In the past, we have also devoted sessions to developing reference and literature review skills, maintaining useful research logs, and occasional playful sessions to build community (e.g., competing to give the worst oral presentation, making stat-themed gingerbread houses). An unanticipated benefit of CIR was the camaraderie and community created at the Monday evening dinners that preceded each research skills seminar session. The meal helped to create a highly visible and cohesive statistics community which was especially helpful for recruitment and retention.

For a sample syllabus, see the supplemental materials online.

4.5 Administration

A number of administrative issues have been encountered throughout the CIR's five-year history. A primary goal has been to demonstrate to the administration that the CIR is a valuable resource for the students and faculty alike. At the outset, there was no course into which CIR activity fit neatly. As time progresses, we remain optimistic that our academic structure will accommodate CIR. As a first step, faculty voted to award students credit for their participation in CIR. However, the statistics faculty are also in need of credit. No faculty credit has been awarded for mentoring CIR teams. The statistics mentors have put in many pro bono hours to make the program a success. An administrative structure to recognize and reward faculty participation in this effort is sorely needed. It is encouraging that the administration granted one course release for CIR faculty for administrative activity, but it is not enough. The recently terminated grant allowed two course releases for administration.

We continue to 'stay on the radar screen' of administrators and faculty to maintain recognition and support for CIR. It is not difficult to sustain awareness for a program like CIR. The intentional diversity of disciplines involved, the fascinating kinds of problems, the exceptional work and recognition the students receive make it easy to foster awareness and garner support for the program. Due to the wide variety of faculty involved, faculty hear about, request to participate in, and support CIR. Parents and alumni read about CIR activities in the college magazines. Furthermore, by now nearly 100 alumni are former CIR fellows. Students in introductory statistics courses become aware of the diverse nature of the field of statistics and its possibilities as audience members for technical and non-technical talks about CIR projects. Prospective students receive materials in which undergraduate research including CIR figures prominently, and they get a glimpse of the CIR room when touring campus. The college commitment to undergraduate research extends even to our hiring when we ask applicants to demonstrate how they might involve undergraduates in research in their field. This awareness of and enthusiasm for undergraduate research, the CIR in particular, is likely to generate the support CIR needs in the coming years.

5. FUTURE OF CIR AT ST. OLAF AND ITS TRANSPORTABILITY

If you are curious about establishing an undergraduate interdisciplinary research program at your institution, you may wonder how the program we describe will translate to other institutions. Is St. Olaf a unique setting better suited to these programs than others? Is NSF support necessary to get such a program going? We address the portability of CIR and the challenges we anticipate facing in the coming years.

St. Olaf College is an undergraduate liberal arts institution with approximately 3000 students located midway between Minneapolis–St. Paul and Rochester, Minnesota (home to Mayo Clinic). The mathematics program is well known for its Big Tent philosophy graduating 60–80 math majors annually. In 1978, many years before other comparable institutions, Professor Richard Kleber started and nurtured the statistics program. Not surprisingly, the healthy mathematics program proved to be beneficial to the statistics program. The statistics program began as and remains a four-course concentration (similar to a minor). A student earning a mathematics degree with a statistics concentration will complete a program very similar to statistics majors in other institutions with possibly more mathematics than some programs. Although we value our ready supply of mathematics majors, the new structure of the concentration admits a much larger number of students who are not majoring in mathematics. This change is consistent with BK's suggestions, and it holds the key to translating this kind of undergraduate research program to other institutions. It does not require the 70 math majors that St. Olaf graduates annually; many of our students combining the study of statistics with other majors are quite effective in the interdisciplinary undergraduate research setting.

Those considering starting an interdisciplinary undergraduate research program may be concerned that a large seed grant is needed. We would encourage such proposals, but we do not feel they are essential to get such a program up and running. Our grant primarily supported students with stipends and travel to present their work. With the termination of our NSF grant, we will have the opportunity to see in the coming years how critical the stipends are, but early signs (18 students accepting fellowships with no guarantee of a stipend for 2009–2010) are promising. If students are motivated more by the experience of research for graduate school applications, intellectual curiosity, or other reasons, there is hope that the program will thrive. We will need to seek out potential sources of funding for student travel. Travel proves to be a valuable experience for many students, particularly those attending meetings such as JSM. However, it is not our belief that stipends or travel are primary motivations for student involvement in CIR.

Initially students' CIR work was not part of their normal course load. The stipend helped reduce the need for an outside job. In a sense, the CIR could be that job and the stipend its pay. With the end of the stipend, it may be more challenging for students who need to work and want to participate in the CIR. We are considering requiring all CIR fellows to sign up for credit, so that it should be no more challenging for them to work than if they had taken any other class.

Scheduling is also a challenge with all of the busy people—students and faculty—involved in the CIR. Obligations to music, sports, and other extracurricular activities necessitated scheduling the Seminar Series on Monday evenings. Although convenient for most (but not all) students, this presented a hardship for faculty. In addition, even scheduling individual team meetings with all the parties involved can be nearly impossible. These considerations are leading us to propose that the CIR be scheduled during a regular class time slot such as a MWF or TTh noontime gathering.

The critical question for St. Olaf College and a question that potential adopters are likely to encounter is faculty support. Our grant did not extend to support for faculty to mentor the research teams. Over the course of the grant, we sought to demonstrate proof-of-concept—that is, the value of CIR as pedagogy and the value of CIR to the campus-wide research community. A course release for CIR administration and an impressive facility for CIR activities provide initial evidence of CIR support. We still need to assure statistics faculty contributing to the CIR that they will be fairly compensated. This is likely to come from either administration granting an additional course credit for CIR or from rearranging existing courses to allow for such a credit. These challenges will also need to be addressed on campuses considering establishing a CIR.

6. CONCLUSIONS

The philosophy and practice of the CIR is consistent with BK's four recommendations. We minimize prerequisites to research, identify ways of fostering statistical thinking, require real-world problem solving, and encourage deep cross-disciplinary knowledge. The seminal features of the CIR are not necessarily place- or funding-dependent. While there are a number of challenges to work out over the coming years, the prospect holds a great deal of promise.

Afterward Attendees at a CIR Dissemination Workshop prior to JSM 2009 in Washington, DC expressed interest and enthusiasm for undergraduate interdisciplinary programming. Five alumni of St. Olaf's program were on hand to describe their own experience and its effect on their career trajectories. With funding, we would be very interested in working with other institutions to begin programs of their own via similar workshops and campus visits.

SUPPLEMENTAL MATERIALS

- **Project Titles and Selected Descriptions and Summary of WSS:** Names and brief descriptions of titles of projects. A calendar of seminar topics along with brief descriptions and sample assignments. (supplemental_materials_11_09.doc)

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