White Paper

Interesting Undergraduates in STEM Careers through Structured Research Internships

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Twenty-Five Years of Experience at the Lamont Doherty Earth Observatory (LDEO)

This White Paper describes the Summer Intern Program at the Lamont-Doherty Earth Observatory of Columbia University, which specializes in introducing undergraduates to earth, ocean and environmental science research. I have directed our program, one of the largest in these fields, since 1990. It draws upon both students from our own Columbia University / Barnard College community and, though our participation in the National Science Foundation's Research Experience for Undergraduates (REU) site program, from other US institutions, as well. Our program serves about thirty students per year, and more than five hundred students have graduated from it. A significant percentage of our graduates have continued their studies in Science-Technology-Engineering-Mathematics (STEM) fields and are now scientists in their own right.

Our program has been constantly evolving. We use pedagogical research results from the educational literature, follow-up interviews of former interns, and guidance based on the experience of other REU sites to make improvements. Consequently, our program has been at the forefront of innovation. The purpose of this White Paper is to document some of the more innovative elements of our program and to encourage others to try them out.

Answering a Research Question in a Well-Structured Setting

Our program is built around the intern answering a *research question* throughout a ten weeklong research project. The question is intentionally a real research question that has scientific value. Originally devised by a prospective mentor, the question is subsequently shaped by the intern through a give-and-take process with the mentor and then answered by the intern during the course of the summer's research.

Few undergraduate students would be able to deal with a real research questions question if left completely to their own devices. The core of our program is the support structures that help the intern conduct research that answers the question in such a way that he or she develops ownership of it.

The Internship as a Trial Career

The goal of our program is to allow a student – even one with no prior research experience - to become sufficiently familiar with scientific research to be able to intelligently decide whether or not a career as a scientist is his or her personal right choice. Furthermore, we work to bring out the student's potential and to give him or her confidence that he or she can succeed in scientific endeavors, so that the choice is a well-informed one. However, if, after the end of the program, the student can give an informed answer, we view it to have succeeded for that student, irrespective of whether the answer is *yes* or *no*.

The ten-week summer internship gives undergraduate students the chance to experience life as a research scientist with a time investment that is an order of magnitude less than that of formal graduate training. Having completed the program, some students will decide to undertake careers as practicing scientists; they will profit by having learned skills that they will soon apply in graduate school. Equally important, however, is the benefit to students who do not stay in the field. The ten-week program helps them make a decision that might otherwise have taken several poorly spent years. Our surveys of graduates indicate that many who decided on a different career pathway made that decision immediately after their summer as an intern.

Stipend Allows Participation of the Economically Less Advantaged

Ours is a paid internship that provides a modest stipend ($5000 in 2014), free housing and subsidized travel. The stipend makes participation possible for many students who simply do not have the economics means to undertake an internship as a volunteer, who might otherwise need to work during the summer to make ends meet. The stipend also signals to the interns that the institution values their work and that they are expected to be responsible and productive members of the community.

Substantive Research Projects Develop Abilities and Confidence

A good research question has several important attributes: its answer must be *unknown* at the start of the summer; and it must be at the *cutting edge* of science. Where appropriate and possible, it should also incorporate research with high societal relevance, for such areas are of especial interest to undergraduate students. By selecting engaging and important research projects, we give the students a feeling that what they do really *matters*. A key element of the student program is that students are active participants in the design of their research project. They do not play the role of mere "lab assistants", but rather that of "junior colleagues" expected to participate in discussions of scientific methods and ideas with their advisor.

In addition, the very fact that the answer to the research question is unknown gives the student a chance to become an expert. As the summer proceeds, they may come to know more than anyone else except their research mentor about this particular subject. At the end of the summer, the intern has the first crack at finding the best interpretation of his or her data. This builds analytical skills and self-confidence.

Mentor as Role Model

Our program begins with the selection of *mentors* from among the scientists at LDEO.

Our goal is select mentors who will engage with the interns, to provide supervision and assistance without either micro-managing them or taking over their projects. Each mentor must make a commitment to meet with their intern on a daily basis, so scientists with a heavy travel schedule are not chosen. Most mentors supervise only one intern, with exceptionally capable advisors supervising two, and so are able to devote significant time to them and follow their progress closely. Many senior professors have an excellent record as mentors, but we do not draw mentors exclusively from their ranks. Many junior scientists and post-docs and even, occasionally, senior graduate students have made excellent mentors, too, because of the high level of attention they were able to give to their intern.

Prospective mentors submit one page project abstracts to a competitive selection process. An abstract describes a possible research question, provides its scientific setting and and tries to interest a prospective intern to answering it. Students are matched with mentors through the application process, which strives to make the best possible match between students' skills and interests and those of their mentor. After reading the abstracts, the applicant selects possible research questions as first, second and third choices. Mentors review the applications, correspond with applicants, and select an intern who is interested in their research question and who has sufficient coursework to pursue it. Immediately after being admitted, interns begin a dialog with their mentors, read background material and think about their project. When they arrive at the start of the summer, they already have some knowledge and can become involved in the research more quickly. An early goal is for them to articulate the research question – possibly modified from the one originally put forward by the mentor - in their own words.

The mentor and other members of research groups serve as role models for the students. The mentors allow the students to see how life is lived further along the career path, often with the juggling of career with spouse and children. The group's graduate students are near peers, who the interns can look up to as models for their own path in the near future.

Safety First!

Many interns arrive without fully appreciating the dangers inherent in many types of scientific research, which can involve proximity to flammable and toxic substances and high energies. Many also have never worked in a close-knit team environment. We provide all interns with formal fire safety training and Title IX harassment prevention training conducted by certified members of the University staff. Interns whose projects involve lab work also receive formal lab safety training; they are not allowed in research labs until they have completed it.

We distribute a list of emergency contact information for all interns to the interns and their mentors before the interns arrive at LDEO. The emergency contact list also includes phone numbers and addresses for emergency services, including police, ambulance and hospitals.

Everyone is cautioned to keep the information accessible and to use it should an emergency arise.

Initial Training Flattens the Learning Curve

Science is notorious for having a very steep learning curve. Many interlocking skills are often needed to make progress on even the simplest of research questions. An intern can easily become overwhelmed by a sense of inadequacy. An important role of the mentor is to flatten the learning curve by providing informal training on technical issues specific to the research project, including the operation of laboratory equipment, software for data access and data analysis, lab and field technique, etc. The mentor's goal is to provide just enough training to allow the project to move forward, without overwhelming the intern. In some instances, the mentor will find strategies for bridging over a task deemed too difficult for the intern, for instance, by lining up a third-party who can assist with some especially difficult step.

Research Focusing Enhances Self-Development

Interns will understand their research projects better simply by being asked, by an interested onlooker, to explain their research question and laboratory methods. An intern who cannot adequately answer such a question knows that further reading of the literature or discussions with his or her mentor are needed. Even more importantly, the questions themselves convey a sense of which of areas of ignorance are the most vital to address.

We provide *Research Focusing* sessions, formal opportunities for interns to talk about their project in a non-threatening setting that allows them to express both what they know and what they don't know, and to receive helpful suggestions from both scientists and peers.

Each intern attends three Research Focusing sessions, in weeks two, four and seven of the program. The three sessions are on: 1) defining the research question; 2) describing the research methods; and 3) summarizing the research results. Each session is attended by three interns, a volunteer scientist (not one of the mentors) and the Program Director. As many sessions are held as are needed to accommodate all of the interns in the program. During a session, each intern makes a short presentation and then answers questions about his or her project for 20 minutes; all participants, including other interns, offer suggestions. In preparing for the sessions, the intern is coaxed into having early interaction with his or her advisor and into thinking deeply about her or her project. In listening to and questioning their peers, the other interns become more knowledgeable about and more invested in research issues. We find that students become very accomplished at explaining their research projects and produce higher quality posters and final papers as a result.

Sometimes the research focusing sessions become trouble-shooting sessions, as the intern describes problems in their laboratory or modeling results. The participants help them come up with strategies for addressing their research problems that can be discussed later with their

mentors. Overall, research focusing produces students with a higher level of understanding of their research project and its societal and scientific context.

These sessions are costly in terms of staff time - we typically hold 10 sessions per week- but extremely valuable to the students. We find that the sessions enable the interns to develop an early understanding of the *big picture* of their research project, something that they might otherwise not achieve until very late in the program. By enabling the interns to learn the overall context of their research early in the program, we produce interns who are more informed and engaged researchers. The sessions also give the interns multiple opportunities to understand both the overall context and details of their research project, allowing those who have less background to attain similar intellectual levels to those who were better prepared.

Special Role of Fieldwork in Building Community

We preferentially select research questions that include fieldwork. Projects with fieldwork are especially attractive to undergraduate students; many are intensely interested in seeing – and measuring – natural phenomena first-hand. Furthermore, fieldwork allows students to experience the most intense method of collecting scientific data. In contrast to an eight hour per day job, fieldwork is a total immersion experience that pedagogical research has shown to be especially effective in learning both content and culture. By its very nature, fieldwork involves rapid adjustment to changing circumstances.

We encourage mentors to conduct a formal pre-fieldtrip meeting with all participants, including interns, to discuss the purpose of the fieldwork, its goals, itinerary and schedule and the intern's specific responsibilities. The intern then has the opportunity to prepare for the fieldtrip through background reading and by obtaining any training that might be necessary, for example, to operate field equipment.

Students that are part of a field team soon recognize that their contributions are essential to the success of the enterprise. This reliance on the team builds community in the research group. Fieldwork also allows the advisor and student to get to know one another more informally, at the end of the day when work is over.

Seminars as a Pathway to Scientific Habits of Mind

Among the many methods that career scientists use keep abreast with developing science are seminars and colloquia given by their peers. More than just communicating content, they build connections between scientists and enhance the visibility of the latest hot research. And they provide a mechanism for enhancing what might be called scientific *culture* or *habits of mind*; that is, a community-wide consensus on what scientific questions are currently considered the most important, what techniques are the most fruitful, and which results are thought to be having the most impact.

We provide a seminar series, intended primarily for interns but open to all the University community, that includes two seminars per week on topics covering a wide range of earth, ocean, atmospheric and environmental topics. We choose lecturers who are all excellent and captivating speakers who can explain their research without extensive jargon. Some lecturers are senior, nationally recognized scientists, but others are younger scientists and senior graduate students who are more likely to be viewed as role models. Interns are encouraged to ask questions during a question period and to have more informal extended conversations with the speaker, after the seminar.

Training in Technical Writing, Oral Presentations and Graphics Enhances Self-Expression

Knowledge that is gained but never communicated is wasted. Career scientists need to be able to communicate their results to the scientific community and the general public; they must have facility in writing papers, presenting posters and giving talks. We provide training in all three of these methods of communication though a combination of formal workshops and opportunities for practice. Interns bring a draft of a three-page research proposal to the Scientific Writing Workshop and take turns reading, critiquing and improving each other's work. Later in the program, they expand this proposal into a 10-20 page final research report, which goes through several rounds of editing by their mentors. The interns develop their graphics skills by attending a workshop, *How to Make a Great Poster,* working with their mentors on graphics, and assembling a poster documenting their final results. The interns develop oral communication skills during the three research-focusing sessions and by giving a one-minute "commercial" for their poster.

We find that over the course of the summer, the students develop facility and confidence in explaining their research project, first to one another and to their mentors, and then to other members of the University community. At the final presentations, students are smooth and confident in explaining their results and the importance of their research. Even originally shy students are confident and articulate at the final poster session.

Posters as Success Stories

The final poster session is the emotional high of the summer. The interns present their research in a poster session that is attended by themselves, their mentors, and many scientists from the University community. The poster session begins in an auditorium, where after opening remarks, each intern presents a one-minute "commercial" highlighting his or her single most important result. We always have an authority figure, such as the LDEO Director, give the opening remarks, because it emphasizes the importance of the program and coveys the institution's respect for the intern's accomplishments. The group then moves to a poster hall and each intern spends ninety minutes explaining his or her poster, one-on-one, with interested attendees.

We make a special effort to let parents know that they are welcome to attend. The emotional support provided by family is vital to any student starting a career, but especially so for students in STEM fields where parents may be completely unfamiliar with the subject matter. Attending allows them to see first-hand how valued are the contributions of their sons and daughters.

Every year, we are impressed by much the interns have achieved. Many will have conducted much more difficult experiments than they initially anticipated, or collected much more data than they initially hoped, or finished with results much more intriguing than they initially imagined. The students are happy *and relieved* to have accomplished so much in such a short time. This sense of closure is extremely important for undergraduates, many of who will now need to turn their full attention to the next semester's coursework.

Research Report as a Durable and Distributable Product

Interns are encouraged to think about the content of their final report very early on in the program. Lines of reasoning brought forward during the Research Focusing sessions are drawn upon in the report's structure. The research proposal that the intern wrote and edited in the writing workshop becomes an integral part of the report, and many of the graphics and some of the text from the poster is incorporated into it, too. However, the main writing effort takes place in the week following the poster session, which is reserved solely for that purpose.

The report sets out the intern's research results more fully than did the poster and documents all of the important technical details that were omitted from the poster for lack of space. The report is structured like a journal article, and requires students to write an introduction that sets their results in the larger context and to cite the scientific literature. The experience gives the interns the important experience of writing a technical report, a skill that will serve them well in both scientific research and technical employment.

The report also documents the research in the way needed by a mentor who wants to follow-up on the intern's results. The availability of the report facilitates inclusion of the intern's work into papers; many interns have become co-authors on their mentor's journal articles by this mechanism.

Positive Impact on Less Advantaged Students

The intern program is particularly effective for students who start the program at a lower level of scientific background and skill. Often, the students who improve most over the summer and who achieve the most superlative results are those from less advantaged backgrounds. They are often the most focused on succeeding; they are the interns who attend every lecture and who take copious notes at every opportunity.

The interns support and assist one another; their interaction is supported by group lunches and by their being housed in a single dorm. A good kind of peer pressure usually develops in which

interns set a high standard for the quality of one another's work. An intern, seeing what is possible, is inspired to improve his or her skills.

Ancillary Benefits to the Institution

The summer intern program benefits the institution as well as the intern. The interns completely change the dynamics of the summer, transforming what might otherwise been a slow time to a period of intense activity. However, because this activity is driven by the enthusiasm of youth and is low-stake, it has a lightness that sets it apart, say, from the tense frenzy that occurs when grant submission deadlines draw near. Most of the projects are in frontier areas of science; mentors and interns alike become excited about still-developing methodologies and nascent scientific hypotheses. Mentors benefit from the energy, enthusiasm and ideas of the students and are inspired to do better science, themselves. In today's highly competitive academic research environment, a proof-of-concept study, conducted by an intern, can be vital to the success of the mentor's subsequent grant proposal. Mentors who are too early career to have large cadres of graduate students especially benefit, because an intern fills a role similar to a Graduate Research Assistant (GRA).

Success as Measured by the Statistics

Since 1982, 11% of our interns have been ethnic minorities and 61% have been women. These percentages compare favorably to national averages in the sciences: from 1982 to 2002, 7% of all earth, ocean and environmental science undergraduates were ethnic minorities, and 8% of the PhDs were awarded to minorities; and similarly, 54% were women and 52% of the Ph.D.'s were awarded to women.

The proportion of minorities in the program has increased over time, from about 7% in the 1990's to an average of 21% for the last 6 years. We believe this success, especially in the case of minorities, to be due both to the supportive environment of our program and to our having achieved a critical mass where minority interns have sufficient peers to feel comfortable.

Several of our graduates who are female and/or ethnic minority are now in faculty positions at colleges. We are extremely proud to have been part of their success stories. However, the number is small enough that we cannot say with statistical certainty that the program improves the rate of academic career success.