Hughes Undergraduate Research Laboratory

Executive Summary

Research is the act of teaching ourselves, an act that is very similar to teaching others. As all researchers are teachers of themselves, it follows that the best researchers ought to make the best teachers if they are provided with formative encouragement to consider the teaching of others as an integral part of their scholarship. Too often in academia there is unnecessary competition between teaching and research—those trained and well-versed in research techniques often have little incentive to participate in teaching. Environments of this type may then contribute to the perception that if one is serious about research, one should avoid teaching. Such environments may interfere with the development of new generations of scientist-teachers who might otherwise view their contributions as teachers to be important.

In order to advance undergraduate education in the sciences, it is imperative that we encourage the development of scientist-teachers. An important goal is to establish teaching as an integral part of research, in both formal and informal ways. I hypothesize that environments in which research and teaching occur together in a seamlessly obvious and simultaneous fashion will encourage students with excellent teaching potential to consider careers with a teaching component. The key lies in making self-learning connect more directly to teaching. I will create an active research group composed of undergraduate students. Encouraging students to experience teaching and learning as part of a research group will make them more likely to envision themselves as future scientist-teachers.

The undergraduate research group will act as an interdisciplinary research team in which both learning and teaching take place. A special laboratory dedicated to the research group will be established. The group will be composed of 10-15 students (primarily juniors and seniors) at one time, or 30-40 students over the course of the program. Strong efforts will be made to include members of traditionally underrepresented groups. The environment of the research group will be designed to remove many of the standard barriers experienced in undergraduate research. The research group will conduct genomic studies of splicing in humans and the malaria parasite *Plasmodium spp*.

Incorporated into this special environment will be elements key to a successful research group:

1) **An engaging set of interdisciplinary questions:** The first goal of the research group will be to create a database of validated alternative splicing events in vertebrate organisms, with a special focus on humans. The group will attempt to identify and validate a fraction of the splicing events judged to be important using microarrays, RT-PCR, and cDNA cloning. The second goal will be to annotate the introns in the *Plasmodium* genome using bioinformatic and molecular techniques. A database will be developed and made freely available on the web.
2) **Access to experts who provide general scientific leadership:** Formal and informal contact between students working on the project and a variety of experts will be established. Local experts—faculty, post- and predoctoral fellows—will be formally engaged in the program.

Additionally, scientists from other academic institutions and industry will be recruited to give presentations and provide feedback to the students on their projects and progress.

3) **Access to sophisticated instrumentation and technology:** The environment for the undergraduate research group will be set up to contain equipment similar to that in use at biotechnology companies. An undergraduate laboratory that contains such equipment is very unusual and will foster the development of sophisticated approaches to the research questions addressed by the group.
4) **Preparation of results for publication:** Members of the research group will be responsible for communicating scientific results. Students will learn to identify and present quality experimental results required for acceptance by other scientists. Results will be published in peer-reviewed journals or on our website after being reviewed by experts in the field.

In order to change the direction of undergraduate education, the university must test novel teaching environments for students and dedicated faculty members. The proposed project would create a powerful environment in which faculty could experiment with creative approaches to the long-term goals of encouraging the development of scientist-teachers, and students could test their skills as budding scientist-teachers. The long-term goal of the project is to establish a new generation of faculty committed to the value of integrated research and teaching. The prediction is that more and better teachers will result as more young people envision themselves in a future environment that nurtures their own desire to learn.

I. Vision and Objectives

A. Current environments for teaching and research in the university

My experience as a professor and a department chair has given me insight into the myriad ways in which the internal machinations of universities can work counter to their goals. Although I have spent most of my time at U. C. Santa Cruz, my discussions with colleagues around the world lead me to conclude that theseare common problems that arise from the forces all universities face. Competition between departments for limited space and financial resources can hinder the development of new and exciting research and teaching relationships. Enrollment-driven resource allocation can push departments to teach more students with fewer and less qualified instructors. Academic standards can erode in the torrent of fear that difficult or expensive disciplines will be unable to justify themselves and be priced out of the university. Social and political forces from outside the university may also warp what a public university is able to do. Public universities are challenged to educate less than well-prepared or motivated students using outstanding researchers who have dedicated their lives to their studies. This is a huge interpersonal, generational, and sociological gulf that must be breached for quality teaching and learning to occur.

Success in this challenging environment depends heavily on the right blend of many ingredients. If there is too much emphasis on research, the faculty will insulate themselves from undergraduates, spoiling the chance for students to learn directly from the masters. With too much emphasis on teaching, the faculty whose own scholarship is rightly of great importance will go elsewhere, diluting the intellectual vigor of the faculty. Too much emphasis on advanced studies, and intelligent students changing disciplines will be unable to do so, inhibiting disciplinary cross-pollination. Too much emphasis on remedial studies, and resources for providing deeper understanding may be unavailable. The hard bargain of the public research university is that it must create both the outstanding research programs to succeed as society's R&D department as well as the means to educate the population as envisioned by Jefferson. These goals must be met without enough money, and without undue disqualification of any student-citizen.

Who really is responsible for how teaching and research is done?

Although administrators, staff, students, the public, and the economy pull the university to and fro, the faculty remains the fulcrum upon which most of the forces are held and balanced. Mysteriously, this concept seems to have been subsumed by the idea that higher education is a service industry, as though diplomas were burgers, and it is up to the faculty to see to it that every customer is satisfied. As it was 800 years ago, the way individual faculty members make their day to day decisions about what is worthwhile scholarly activity remains the major force that shapes the university. In a perfect world, the wisdom of well-examined values would guide faculty as they make these many tiny but key decisions. In reality faculty are greatly influenced by morale, petty personal victories or defeats, the effort needed to care for their children and parents, or their inability to afford a house. In order to change direction, the university must manipulate the environment of the students and faculty members who share the best vision of what the university can be, to encourage them to make their vision become real. Manipulating the environment means removing damaging disincentives to a fair balance of teaching and research, and creating powerful incentives that steer faculty energy toward creative approaches to the goals of the university.

What can one professor do?

As a faculty member, I recognize that there is only so much I can do to influence the path of university practices, even with support from HHMI. I am not an educational theorist who will develop the grand synthesis on teaching and the function of universities. I am an intuitive practitioner, having had no formal training in teaching. I do not recall coming across the word *pedagogy* until I was an assistant professor, at which time it was suggested that I develop one. A look in the dictionary revealed that the word is derived from the Greek *pedagogue*, the slave responsible for taking the children to and from school. This etymology did not encourage me. If I were an evolutionary educationalist I would hypothesize that there is a large genetic component to individual teaching ability, since there must have been great selective pressure for self-teaching and learning ability during the evolution of intelligence. Although as difficult to address as similar suppositions about the components of intelligence itself, such a hypothesis would no doubt annoy many of my colleagues engaged in the teaching arts. It would also reveal that I have limited hope for the development of techniques that will turn poor teachers into excellent ones, although I certainly believe that talented teachers can improve. Given my own biases in this area, I have been more interested in observing specific individual scholars in action, and the environments in which they operate.

I propose to examine the structural aspects of the environments in which teaching is done, rather than focusing on myself as the teacher. The specific aspect I wish to address is the way teaching as a cultural practice is transmitted from one generation to another, in order to encourage students with excellent teaching potential to enter careers in which teaching is a part of the job. I think the key is to make self-learning, which is an intrinsically self-satisfying activity, connect more directly to teaching, which is an altruistic activity that generates satisfaction in the teacher indirectly through its effect on others. The quality of any research environment will be compromised by the absence of any serious teaching activity. Conversely, the quality of any teaching environment will be compromised by the absence of any serious research activity.

Research is the act of teaching ourselves, and is accomplished using the same elements we should be using to teach others. As an experienced student, I have found that the best teachers are also immersed in research and scholarly activity of their own design. This obvious foundational element of the research university seems in danger of being swept away by the creeping push to codify a set of proven approaches that any teacher can apply to any student, and which produces immediate results that can be quantified by some approved standard of teaching effectiveness. Efforts in this direction often ignore the fact that teaching, like intellectual curiosity, is a self-originating, personal, continuously experimental, and highly empirical activity, the effectiveness of which may not be apparent for decades or generations.

Better teaching will happen when more young people envision themselves in a future where they enjoy the role of teacher in an environment that also nurtures their own desire to learn. To test this notion, which arises from my own experience as a student, I propose not to take up a statistically significant clinical study of how people learn that they love research and teaching. Rather I propose an experiment in which I attempt to create the environment of an active research group composed of undergraduates. I predict that by encouraging students to experience teaching and learning as part of a research group they will be more likely to entertain positive visions of themselves in future action as teachers.

B. Specific objective.

My hypothesis is that participation in a learning environment focused on discovery reveals to undergraduate students a vision of themselves as future teacher-scientists. The paucity of such environments limits the number of students who recognize this potential in themselves. Defining and operating an environment as outlined in this proposal will provide a test of this hypothesis and allow more undergraduates the opportunity to become part of an interdisciplinary research team in which they both learn and teach. This will take the specific form of genomic studies of splicing in humans and the malaria parasite *Plasmodium spp*. in a special laboratory dedicated to the project.

C. My teaching activities will change

My current formal teaching effort includes *The Human Genome* for nonmajors, *Yeast Molecular Genetics Lab* for majors, and the RNA processing module for *Advanced Molecular Biology* for first year grads, and half of *Microarray Applications and Analysis* for graduate students in Molecular, Cell & Developmental Biology, Bioinformatics, and Computer Sciences (shared with Todd Lowe). Since I intend to maintain my research activities, I expect the project will occupy the time I currently spend on teaching these courses, and I intend to negotiate this issue with my department chair. Since the project proposed below contains a large laboratory activity component, I expect that I will be teaching much of the same material, but doing it quite differently. I also expect that the effect of being identified as a Hughes professor engaged in a program of this type would require additional time for meetings and discussion with HHMI and other research and educational organizations. As I am scheduled to step down as chair, my administrative duties will be greatly reduced during the project period. Following the end of the project I would remain available for continuing assessment of the impact of the planned activities. If considered successful, the activities could continue.

My proposed activities will differ greatly from how I teach now. Rather than focus on a digested body of extant information, I will focus on teaching the processes needed for understanding a comprehensive and evolving problem through research. During this research, issues will arise that demand self-education in a particular topic area, either through reading of the literature or experimentation. My activities will be devoted to organizing students into teams that address certain specific parts of the larger problem. Rather than telling them what I think they should know, I will be helping them analyze the deficiencies in their knowledge relative to what they need in order to proceed with the project, and directing them toward the resources and experiments necessary to answer their questions. In some cases the resources I will identify will be other students in the group who may have complementary skills and knowledge. They will be required to teach others in the group what they learn. Because the context of this exercise is genomics, the essential concepts of genetics, molecular biology, protein structure and function, physiology, and evolution will be illuminated as a consequence. With help from colleagues in the computational biology group at Santa Cruz, the applications of computer science and mathematics to problems in biology will also be addressed.

II. Specific activities

A. A special environment for undergraduate research

In the biomedical area, most undergraduate research is done in association with a principal investigator in a laboratory space assigned for the investigator's research. Often such space is at a premium, and faculty investigators tend to view their space allocations competitively. Priority in assigning space within a lab is given to postdoctoral fellows and graduate students, whose efforts are more likely to result in productive research. If there is any space left over, an undergraduate student who is persistent may be allowed an opportunity to do research. Expectations are generally low and the professor will often delegate supervision of the undergraduate to a grad student or postdoc. This environment represents a significant opportunity for aggressive self-learners who are not intimidated by the pace and hierarchical structure of an active biomedical research laboratory. Access to sophisticated instrumentation and technologies as well as contact with renowned experts can make such an experience seminal in the life of a budding scientist. Occasionally the work done by undergraduates finds its way into the literature.

My proposal aims to remove some of the standard barriers and expand elements of this experience in a way that does not dilute its impact, in order to determine whether more students can benefit from research experience as undergraduates. Elements I believe to be key are 1) an engaging set of interdisciplinary questions, 2) access to engaged experts who lead thinking, interpretation of results, and experimental design in a general way, 3) access to sophisticated instrumentation and technology, and 4) preparation of results for publication. In the proposed program, these elements would be available to the undergraduate population not one or two slots at a time in 15 different laboratories, but in a single laboratory dedicated to participation of 10-15 hand-picked undergraduates and the important questions under study. The students will work together as a team each quarter, receiving academic credit for their efforts toward a common goal. Below I specify how I propose to maintain the four key elements in this novel context.

Element 1: An engaging set of interdisciplinary questions.

There will be two general goals for the project. The first will be to create a database of alternative splicing events in vertebrate organisms, with a special focus on humans. Much of the data that describes these events is not entered in public databases and cannot be automatically annotated. Although this is changing, automated annotations of splicing have large noise components that still require human inspection to remove them. I propose to capture data concerning splicing for genes that are conserved in various metazoan species, in order to compare splicing patterns across species. In addition to identifying alternative splicing events that are conserved (and not conserved) in metazoans, we will identify alternative splicing events that are polymorphic between members of the same species, especially humans. This has never been done systematically. The database will be freely available on the web. We will also develop microarrays that detect alternative splicing events that we deem are interesting from our analysis of the database. We will attempt to validate these alternative splicing events using microarrays, RT-PCR, and cDNA cloning. The second goal will be to annotate the introns in the *Plasmodium* genome. This goal will be approached using bioinformatic and molecular techniques. Many gene predictions are available for the malaria agent, and an EST project is underway. We will extract and represent this data with respect to splicing on our own website, as we already have for the yeast genome. We will design microarrays to validate intron predictions as well as perform other sorts of validation experiments.

Element 2: Access to experts who provide general scientific leadership.
This feature of the proposal is extremely important, and may be the most informal yet critical property of the environment I would try to create. The definition of "experts" should remain broad, in order to encompass both graduate student and postdoctoral scientists who though expert are not widely recognized, as well as recognized individuals who may be short on experimental details but long on perspective. In order to generate this feature of the environment I will endeavor to create formal and informal contact between students working on the project and a variety of experts. I will maintain primary contact through weekly lab meetings, and through office hours. The format of the weekly meetings will be the reporting and discussion of progress over the previous week. Teaching assistants provided by the department will support the activities of the project each quarter, which will be considered equivalent to an upper division laboratory course. The teaching assistants will be selected from among graduate students working in genomics and genetics of model systems in the department, as well as computational biology graduate students in the Computer Sciences department in the School of Engineering. The teaching assistants and I will attend and provide feedback and direction concerning the efforts of the coming week. The goal here will not be to micromanage the activities of each individual, but to convey the message that we are concerned with the level of progress and are dedicated to getting the next right things done. The responsibility for accomplishment will remain with the students, and the teaching assistants and I will take notes so that we can evaluate how the participating individuals use our advice.

In addition to local experts formally engaged in the program, I will recruit local individuals to give presentations and provide feedback to the students. These individuals will be postdocs, faculty, and industry scientists from around the San Francisco Bay area. Their participation will be requested as part of the program, and they will receive honoraria for their endeavors. Here the idea is to have the students hear many different approaches to a variety of related problems and to have people with a variety of perspectives look at what they are doing and comment. This experience will provide students with a broad perspective on the contexts in which science can be done, and the unexpected ways in which their own work can be viewed by others.

Our department maintains a high quality seminar program with outside speakers who are in general high visibility leaders in their fields. Students in the program will be strongly encouraged to attend the seminars. I will schedule a meeting with each seminar speaker during their visit in order to have students meet them, describe what they are doing and obtain feedback on the project from the visiting speakers. In this way students can relate the scientific work described by each speaker with the person leading the work, make their acquaintance and receive their impressions of the work the students are doing.

Element 3: Access to sophisticated instrumentation and technology.

Genomics as a science has evolved from genetics and molecular biology through the application of robotics and miniaturization. The primary reason for this is that the gene characterizing activities performed by geneticists and molecular biologists one or a few genes at a time has been extended to every gene in the genome. This revolution continues, however unlike many scientific revolutions, this one frankly has left the academy behind. This is not to say that universities have not made key contributions; rather that the scale and sophistication of the engineering required to carry out genome-level molecular biology activities are beyond the resources of most academic biology departments. Concomitant with this change in scale and mechanization has been a change in research team structure and size. In genetics and molecular biology, the small academic laboratory was an adequate venue for significant discovery. In genomics there are hardly any publications that do not come from consortia of academic and industry research laboratories, primarily because resources and microengineering know-how is to a large extent vested in the industrial sector. It is valid to ask how academic departments will adapt to taking weak positions in this area while maintaining the integrity of their research efforts and their responsibility to educate students of genomics.

An important feature of the research environment I plan to create for this project is that it will contain equipment similar to that in use at biotechnology companies, for example, microarrayers, automated sequencers, DNA synthesizers, colony pickers, microtiter plate handlers, scanners, liquid handlers, and other instruments. These will be purchased with Hughes funds or donated by area companies. It is expected that donated equipment may not be the latest model, but will be of great utility for training purposes. The equipment will be set up in and near the space devoted to the project, and the equipment will primarily be used for the project. I will need to negotiate the availability of such a space with my Dean, however our department is blessed with adequate teaching laboratory space and I anticipate that with minor remodeling, such a space would be available. An environment for undergraduate research that contains such equipment will be very unusual and will foster the development of sophisticated approaches to the research questions addressed by the group. It is anticipated that the undergraduate research group will be the primary user of this equipment. Whereas many undergraduates are only briefly exposed to the conceptual approaches of genomics in their genetics courses, this group will receive intensive exposure to the conceptual approaches, the tools, and the practices of genomics in a results-oriented research environment.

Element 4: Preparation of results for publication.

A key element of the environment I wish to create will be the responsibility to communicate scientific results. By emphasizing this, I will be preparing students to identify quality measurements they need in their experiments in order to present them and have them accepted by other scientists. I will generate this emphasis by helping students read and critically analyze the published work of others, in order to define for ourselves what we accept as a result or an idea that helps lead to the next hypothesis. To the extent possible, we will publish our results in the primary literature. Where this is not possible or impractical due to the nature of the data, we will publish it on our own website, after revision in light of comments on the work made by trusted reviewers.

Mechanics of admission to the group.

The success of this activity will be dependent on the motivation of students. The target group is undergraduates interested in the topic areas, who may not have recognized in themselves their potential as scientist-teachers. Of special concern will be students from groups traditionally underrepresented in the sciences. U. C. Santa Cruz has an outstanding record in engaging underrepresented students in the sciences, most notably through its NIH Minority Access to Research Careers (MARC) and Minority Biomedical Research Studies (MBRS) programs. I anticipate that the proposed project will interface well with those programs since they require a laboratory activity that would be fulfilled by participation in the envisioned Hughes project. I will require an application from each student including transcripts, SAT scores, and a statement of purpose. I will prioritize the applications and offer slots in the program based on my judgement of the likelihood that they will succeed. They will be on probation their first quarter and will be allowed to continue provided their performance is adequate. Since the group will be composed of students majoring in computer science, engineering, biology, and bioinformatics, some component of admissions will be sensitive to balancing expertise within the group. Students may take the course every quarter provided there is room in their schedules. Juniors, seniors and advanced sophomores will be eligible. As students graduate or complete their studies, new students will be admitted each quarter.

III. Expected outcomes and products

If the proposal is supported I intend to use the first year to establish a space commitment from the university, obtaining course approval from the department, setting up the laboratory, ordering equipment, advertising the course, and identifying students. In the second year through fourth years the course will take place. If the lab engages 15-20 students, half or more of whom graduate each year, the program will serve about 40-50 students. During this time the annotation of splicing patterns generated during expression of the human genome will be in its peak phase, and I expect the group to contribute to the larger endeavor through publication in print and on the web. Similarly the *Plasmodium* intron annotation, if our experience with yeast is any indication, will require committed attention in order for reliable results to accrue.

IV. Assessment and dissemination

During the course of the project, especially in the first few quarters, we will rely on anonymous student evaluations for feedback as to the relevance of the activities to the stated goals of the project. In the long term, the proposed project has two main elements to be evaluated. One element consists of research, and the consequent scientific progress made by the project. I will evaluate the success of this aspect of the project by estimating the significance of the published research results. Utility of the web-based materials will be estimated by access logs. The second element is the impact of the program on the career trajectories of the participants. We will maintain contact with participants and track them into their chosen careers. Periodically we will invite alumni to comment on the impact their Hughes experience had on their career. These data will be made available in an appropriate report.