Enhancing Undergraduate Education: A REU Model for Interdisciplinary Research

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ABSTRACT
This paper presents a successful model for undergraduate research where student participants work on interdisciplinary research projects; in our case, at the frontier between computer science and medicine. Students are part of research teams comprised of other undergraduates, graduate students, faculty and medical experts, participate in professional development and training activities within the larger group, and disseminate their results at the host institutions or conferences specific to the interdisciplinary focus. The model outcomes at the end of the first three years (2005-2007) indicate that the interdisciplinary model successfully 1) expanded the student participation in research by recruiting students who might not otherwise have research opportunities, 2) attracted a diversified pool of talented students into science, 3) promoted interdisciplinary undergraduate studies in computer science and medical informatics as well as in future graduate studies; and 4) trained students in all phases of research, including writing and presenting research papers at conferences.

Categories and Subject Descriptors
K.3.2 [Computer and Information Science Education]: Computer science education

General Terms
Design, Management

Keywords
Undergraduate research, interdisciplinary research, medical informatics, MedIX, REU

1. INTRODUCTION
In the past five years many universities have significantly changed their general education to address some of today's most intellectual challenges such as the changing demographics of the undergraduate population, shifts in knowledge, technological advances, and increasing emphasis on "transferable" skills. Most of the changes in the general education addressing these challenges relate to increased writing (65% of the research universities), preparing students for global environment (60%), fostering interdisciplinary programs (53.4%), and enhancing and facilitating research experiences (39%) [1].

While the main approach to integrate interdisciplinary research in undergraduate education is through curriculum (freshman seminars, courses that connect science and the humanities or science and society) [1], summer research programs [2-6] have offered other successful ways to strengthen the undergraduate education and lay the foundation for future learning.

In this paper, we present the NSF Research Experience for Undergraduates (REU) summer program at DePaul University and Northwestern University, a model that addresses the above challenges through an interdisciplinary undergraduate research program at the frontier between computer science and medicine. The findings reported in the paper are based on the summative and formative evaluation performed on the data available at the end of the first three years (2005-2007) of our REU program.

2. INTERDISCIPLINARY EXPERIENCES
As Salakoski [8] states, "The exact sciences, such as mathematics, statistics, computer science or physics, are based on theory, i.e. they are used to calculate how things should be. On the other hand, the biosciences, biology, chemistry and medicine are experiment-based sciences, where empirical observations play a central role". Therefore, interdisciplinary programs are needed to 1) *bridge the methodological gap* between the theory-based study of information technology (IT) and the empirical practice of the sciences and 2) *provide early experiences* that situate information technology in real-world settings. One of the reasons to choose medicine as an interdisciplinary focus is because the demand for individuals who see their career opportunities at the intersection between information technology and medicine has never been higher and far outstrips the current supply [7].

Moreover, several research studies [9, 10] have shown that the context of computing is often very important for many women and minority students. Embedding science and technology in their social context, such as medicine, the arts, and space exploration, can significantly impact the number of individuals choosing careers in science and engineering. These interdisciplinary programs are expected to become an attractor and motivator for a diverse student population who do not see the direct need for a computer science degree. In particular, students working in the area of medical informatics are more acute to the immediate applicability of their research work; the students' close interaction with medical experts can also help them understand that their

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work will help build a more unified environment that requires minimal computer training for medical experts and fits smoothly into the medical practice workflow. Summer research programs in medical informatics such as the one hosted by DePaul University and Northwestern University and founded by the National Science Foundation REU program [11] can offer those students the right opportunities to perceive the importance and applications of computer science and continue their education in this field.

For institutions without medical informatics programs, medical schools or without collaborations with medical experts, it is difficult to offer medical informatics opportunities to their students. However, most schools can likely find an interdisciplinary focus of another kind, which will still provide many of the benefits described above. From the 42 REU sites listed on the NSF REU program website [11] as of October 2008, 4 sites are in medical informatics (3 in bioinformatics and ours in imaging informatics) and 4 others focus on other interdisciplinary topics (such us science of design in computer science, engineering, and math and interdisciplinary graphics research).

3. THE MEDIX REU PROGRAM

3.1 The MedIX Program Structure

The MedIX program [12] was designed to allow the research participation of 8 students each summer for 10 weeks, with the majority of the students coming from other institutions than the hosting one. The research environment was provided by two interdisciplinary laboratories, the Medical Informatics Laboratory at the School of Computing at DePaul University and the Imaging Informatics Laboratory at the Department of Radiology at Northwestern University. Four mentors, consisting of three computer science faculty (including two females) and one medical doctor, supervised the research work of these students. All mentors had previous experiences supervising undergraduate research and collaborating on medical informatics projects.

Each summer session began in mid-June and involved some follow-up activities during the subsequent academic year. Students were often grouped in teams of two to help reinforce the positive aspects of teamwork. In particular, students were paired across disciplines when possible, so that, for example, a computer science major would be paired with a biology major. Individually, each enrolled student was conducted research as part of a larger group, presented research results to the research group as well as other audiences, wrote up research results in the format of a conference or journal article, and disseminated project information through the web. In addition, participating students attended conferences and joined professional organizations.

3.2 Recruitment Activities

The recruitment stage consisted of three phases: 1) contact with interested representatives at target institutions, 2) contact with students at target institutions, and 3) the actual application phase.

The contact with interested representatives at target institutions began with an email to IT departments of local two and four year institutions without research programs in the local area. Based on the response, the Principal Investigators identified interested representatives from these various schools who actively identified potential applicants and posted advertising bulletins.

The contact with students took place in two stages. In the first stage, students identified by institutional representatives were given application materials and encouraged to apply. The second stage involved attracting the attention of students who have not been individually identified. We advertised the MedIX program through faculty, flyers, mailing, informal information sessions and the school web site. Faculty members at both the target and host institutions teaching intermediate and advanced IT courses were asked to make announcements about the REU MedIX site to their classes. Flyers were posted on bulletin boards. We also created a web page advertising the program and asked all participants to provide a link to it. Finally, we contacted local professional organization such as ACM-W, NSBE, and the honor society Upsilon Pi Epsilon (UPE) and asked them to assist us in the recruitment process. In the sequent years, the recommenders and the REU participants from the previous years were asked to help with the recruitment process.

The actual application process involved the collection and evaluation of applications. Starting with the end of January and until middle of March each year, the application process was available online to all students interested in undergraduate research experiences. All the applicants were reviewed by all four mentors participating in the program and, by the end of April, the selection of the final candidates was over and all the students knew of their participation in the MedIX REU program. Each applicant was evaluated and ranked on a scale from 1 to 5 giving more importance to the following items: gender and minorities, first generation college students, GPA above 3.0, recommendation letters, major related to the MedIX interdisciplinary area, and intention to go to graduate school. Special consideration was given to candidates who did not have any research experience or a graduate program at their home institution, but expressed strong interest in research and/or graduate school.

3.3 Training and Development

In the first week, students were extensively prepared for their research projects in two ways. The first involved general tutorials on image processing, medical image processing, machine learning, and two software packages, MatLab (for image processing) and SPSS (for machine learning and statistics); this provided students the basic knowledge for all the projects which were specifically tailored for undergraduate students and had measurable goals that could be completed within a 10 week period. Other interdisciplinary programs would have training appropriate to the non-IT piece of the program. The second involved individual talks by all the mentors on the individual projects that they were sponsoring. Each of the mentors proposed several projects whose original complexity and goals (as posted on the program website during the recruitment phase) were sometimes adjusted to both match better the students' background and still lead to research outcomes. Combined, these tutorials and talks used the better part of the first four days of the program. At the end of the first week, the faculty-students teams were formed by having each student chose a research project that fitted best his or her academic background and research interest and teamed students across disciplines when possible.

During the following nine weeks, students participated in bi-weekly group meetings to report on their progress, brainstorm with one another, and test their hypothesis. In order to improve

their oral and writing presentation skills, the students had to give two formal presentations and submit a final report. In addition, they presented informally and provided bi-weekly progress reports throughout the program. The bi-weekly progress reports were structured in the format of research papers which, through multiple iterations and feedback received from the mentors, became the final papers and were submitted to conferences at the end of the program. Given that the mentors strongly encouraged the students to disseminate their work outside of the REU programs by participating in conferences specific to their research, several seminars ("Retrieving and reading research papers", "How to make a research presentation", and "Getting your work published") were organized each year to prepare students for giving good presentations and writing research papers. These presentations are available from the authors.

One-on-one faculty mentoring and REU student meetings were also held to ensure a more focused interaction on the specific research problem. In addition to the intellectual exchange, these meetings provided a great opportunity to discuss future plans with the students, career choices, pursuing a graduate degree at the Master or PhD level, as well as sharing the mentor's personal experience as a graduate student and a professor.

Furthermore, special events were organized to get students motivated in doing research and to help them pursue careers in science. For example, each summer the NSF REU site in Medical Informatics organized the following events: 1) "A Day in the Life of a PhD student" panel discussion in which the REU students learned from several PhD students about what it takes to do and love research, their experiences and challenges being PhD students; 2) 'Developing a Research Career' seminar where students were taught the basic steps of becoming a researcher starting with graduate school and ending with becoming a full professor or a researcher in industry and 3) 'Research projects at DePaul' round table where students met local faculty and learned about their own research projects, grants, and students.

3.4 Interdisciplinary Research Projects: Design and Examples

There were 17 projects in total, 12 being performed at DePaul and 5 being performed at Northwestern University. Although we exemplify below only three of these projects, all the other projects are described on the MedIX website [12].

Each of the projects involved in the proposed REU site had well-defined goals, interesting applications, and challenges for participants of all levels. The research projects were designed such that the background and programming skills of the students were fully exploited during their research experience; at the same time, the projects were designed to enhance students' analytical skills, develop passion for discovery at the frontiers between computer science and medicine, and make that zone of transition from undergraduate to graduate student easy to enter and cross.

Furthermore, the projects were designed to represent current and vital research areas and to give the students a sense of the importance of their work and research in general. The interdisciplinary nature of the research projects helped broaden students' horizons and helped them gain an understanding of how different disciplines are connected.

In particular, one of the students deployed an open source program, 3D Slicer, to the research environment at Northwestern. Slicer (www.slicer.org) is "freely available, open-source software for visualization, registration, segmentation, and quantification of medical data" that is now a component of the National Alliance of Medical Image Computing (NA-MIC). It also offers the ability to add in user defined modules that extend its functionality for specific needs. While providing very advanced visualization functionality, the software lacks integration into clinical workflow and more importantly a graphical user interface that could be navigated by a radiologist in the course of a clinical interpretation session. He took the source code for Slicer 3 and modified it so as to be incorporated into a diagnostic workstation currently under development in the Northwestern laboratory [13].

Two other students working at Northwestern completed work on automatic breast density estimates in digital mammography [14]. Their preliminary results showed promising evidence that an eXtensible Imaging Platform Volumetric Breast Density Assessment would be a reliable method for assessing breast density and their method's evaluation of breast density was in agreement with two previously accepted techniques.

Finally, while most of the contributions from the students working in the DePaul lab were primarily information technology contributions, they were designed around problems outside the discipline and had immediate application in medicine. For example, the content-based image retrieval (CBIR) system for lung interpretation (Figure 1) developed during summers 2006 and 2007 offers utility in teaching and research for radiology [15].

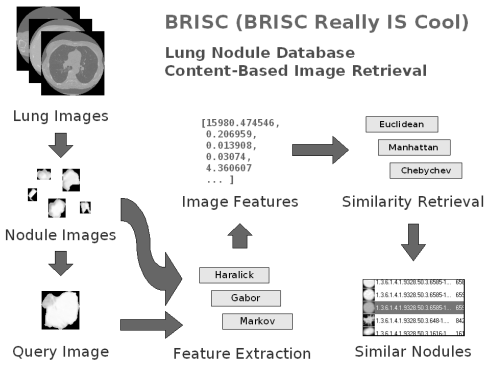

Figure 1: Overview of the CBIR system

4. MEDIX PROGRAM OUTCOMES

4.1 Statistics on Participants' Demographics and Prior Research Experience

There were 26 students (8 - year 1, 9 - year 2, and 9 -year 3) participating in the MedIX program 2005-2007, one who came with her own funding through the Hughes Medical Institute and another one supported from additional funds. Their median age was 21, ranging from 19 to 22 with the exception of one student who was between 35 and 40 years of age; nearly half of the students were women (46%). None of the participants were freshmen, 12% were sophomores, 27% juniors, and 61% seniors. These percentages represented the right mix in having students at the beginning of their undergraduate program to explore the

avenues of research through the MedIX REU program and senior students with more experience at working in teams and a more solid academic background for whom the publications and presentations at conferences helped them get into graduate school.

Over half (58%) of the students' home institutions did not offer the PhD degree in fields supported by NSF. Fewer than half reported that they had (other than for course work) previously given a visual (poster) research presentation (31%) or an oral research presentation (27%), authored or co-authored a publication in an academic journal (12%), or in the previous two years been involved in any research projects (42%). When asked how much time they had spent in a research environment, 92% reported no experience in an industrial research environment, and 58% reported no academic research experience.

In terms of the geographical distribution of the participants, they came from 12 different states with the predominant number of students being from Illinois (35%). The academic background of the students spanned the following programs: computer science, math, biomedical engineering, electrical and computer engineering, biology, and biopsychology.

4.2 Student Accomplishments

All students worked on interesting and current problems in the medical informatics field and learned about research and graduate school through the REU activities performed over the summer.

The MedIX REU has produced an impressive number of student co-authored publications: 16 conference publications, 1 journal paper, 9 extended abstracts and posters, open source software, a Computing Research Association (CRA) Honorable Mention for outstanding undergraduate research (2006), and a Top Math Poster Award (2007). All the co-author students presented their work at the conferences in which their work was published; of the 26 students participating in the program, 22 (85%) coauthored at least one paper or extended abstract. Besides continuing their research work to finalize the camera-ready manuscripts, 3 students continued their work through honor theses and senior projects. This is a remarkable success rate for undergraduates in producing professional-level products after just a 10-week research apprenticeship program.

The following answers from the surveys are illustrative examples that the students wanted to gain research experience and learn about research, prepare for pursuing a graduate degree, improve their writing skills, publish a research article through the REU program, and be involved in interdisciplinary work:

"I wanted to have some research experience in a field parallel to my degree before I applied to graduate school, as well as experience that would be valuable to future employers."

"I believe that if I'm able to master the essential skills through doing this program, such as MatLab and reading research papers, I would have succeeded in just gaining experience. I also believe my success would be defined by having my research published."

"I have attended a previous REU and really enjoyed the work and atmosphere and I wanted to repeat this experience in a place where I have a better chance to be published.

We believe that our main contributions to the success of publishing papers co-authored by undergraduates are our strategies described in Section 3.3 which we outline them here again: close interaction of faculty mentors and graduate students with undergraduates, well-designed projects with clear goals, teams of students with complementary skills, reading and reviewing papers related to the projects throughout the program and writing assignments in format of biweekly reports reviewed by mentors and leading to the final project paper.

4.3 MedIX Impact on Career Choices

If at the beginning of the REU program, most of the students were not decided about going to graduate school; at the end of the program at least half of the students expressed interest that they would like to pursue a graduate degree. The post-REU survey responses indicated that students' interest in graduate school had increased by the end of the 10-week program, but were the effects lasting? In the follow-up surveys sent several months later, students were asked whether they planned to attend graduate school. Of the 16 students who responded to the survey, 15 indicated that they planned to enroll in some form of graduate or professional school. Most (10) intended to do PhD or other graduate work in computer science, 1 planned to attend graduate school in a science other than CS, and 4 were applying or accepted to medical school (one in an MD/PhD program). At least five are currently attending graduate school in pursuit of a PhD with fellowship support.

Most of the students came from traditional CS programs, and were unaware of the medical and bioinformatics applications of computer science. In response to the question "How has participation in this program changed your perspective on computer programming and computer science?" the most frequently cited effect was that it increased appreciation of the practical/interdisciplinary applications of computer science (9):

"I see more possible applications of CS and how vital it is in other fields."

"Yes, I believe that computer programming has a much larger range of people it can help than I previously thought. Computer programming affects almost every aspect of the world."

"I have learned that I can apply it to the medical field and not just in a cubicle typing code or something."

For some of those students, the ability to work on medically-related problems injected interest and relevance into their undergraduate education and will likely influence their graduate school choices. In contrast, one student who was from a non-technical background stated that her ability to work on technical problems will likely influence her final choice of careers.

Furthermore, there was an ever growing trend over the three years: more students from non-technical majors were applying and participating in the MedIX program. We see this as strong support for the interdisciplinary nature of the program and also as a way to educate future doctors, biologists, and geneticists about the benefits of technology in their careers. A student comment from one of the semi-weekly process log surveys made clear the impact the program had:

"This has probably been the single-most influential experience in my undergraduate career in terms of steering me towards what I want to do when I graduate. I am enjoying it immensely."

We believe that the success of the interdisciplinary aspects of our program was related to our strategies in having students work closely with medical doctors, visiting imaging modalities labs at the Northwestern Hospital (such as the computed tomography and the mammography labs), showing the students the entire workflow from patient data acquisition to image interpretation and diagnosis, and tailoring their projects along the real-world examples and problems they saw during the visits to the hospital.

4.4 MedIX Impact on the Host Institutions

For the last four years, two of the computer science mentors have pursued available undergraduate research support from both DePaul and the School of Computing. This continuity of research has enabled local students to continue the work begun in the summer. Furthermore, the principal investigators received a commitment from the Dean for the creation of a new lab for hosting undergraduate research activities. This new lab called the MedIX lab has been the research home of many undergraduate students participating in research, including the 26 REU students from summers 2005 - 2007. The Dean later approved additional funds for local students participating in the MedIX program to continue their funded research throughout the academic year. Given the success of the MedIX program and the rising interest in undergraduate research, the DePaul School of Computing also approved the introduction of a new course (IT300) as part of the student experiential learning requirement. In regards to tenure and promotion, the REU MedIX program had a substantial role in the decision process. Finally, the success of the REU program encouraged a supplementary grant to support undergraduate research on an existing NSF grant, which in turn led to another REU grant for the 2008 – 2010 period.

5. CONCLUSIONS

Through the MedIX program, students worked collaboratively on meaningful, challenging problems that have real-world application, and successfully produced useful applications and professional publications and presentations. These achievements, together with the survey data from faculty and students, clearly show that the program has:

- Expanded the student participation in research by recruiting students who might not otherwise have research opportunities, such as students at academic institutions where research programs are limited
- Attracted a diversified pool of talented students into science;
- Promoted interdisciplinary undergraduate studies in computer science and medical informatics
- Facilitated students learning on how to solve a "big" problem in a limited time
- Taught students how to work in interdisciplinary teams
- Taught students how to write a research paper and submit it for publication

Finally, the student survey responses and the number of students in the follow-up surveys who reported an intention to pursue a graduate degree argue strongly that the MedIX program successfully promoted graduate studies for talented undergraduates. We believe that our program can serve as a model for any institution looking to foster interdisciplinary programs and provide enhanced research experiences starting at the undergraduate level.

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