Mentoring Undergraduates in Computer Vision Research

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***Abstract*—The future of our society will be shaped by the young and talented minds going through our colleges and universities today. During the last 14 years roughly 130 undergraduate students from several institutions have participated in our research experiences for undergraduates (REU) program funded by the National Science Foundation (NSF). A large fraction of our students have been able to prepare a paper for submission to a conference, have the paper accepted, and then attend the conference to present the paper. Several participants have even accomplished enough substantial research to result in journal publications. Many past participants are now pursuing graduate studies at various institutions. In this paper, the REU model is described in detail; some examples of student success are discussed; and some observations are summarized.**

***Index Terms*—Computer vision, National Science Foundation (NSF), research experiences for undergraduates (REU), undergraduate research.**

I. Introduction

In 1987, NSF started a new program, research experiences for undergraduates (REU) (http://www.nsf.gov/home/crssprgm/reu/proganno.htm for more information). The goal of the REU program is to encourage talented students to pursue graduate studies and realize their full potential in this regard. There are two types of REU grants: supplements and site grants. REU supplements to existing research grants can be obtained to support one to two undergraduates. The aim of an REU site is to provide research experiences to a group of eight to ten undergraduates. The site participants are typically from different schools, and the experience emphasizes group activities. The REU site can run for the summer only, for the academic year (fall and spring), or for the calendar year.

The Computer Vision Lab at University of Central Florida has hosted a national site for NSF REU since 1987, with Computer Vision as the research area focus. Computer Vision deals with recovery and use of information about objects present in a scene from images of the scene. The information about objects may include shape (two-dimensional or three-dimensional), location, orientation, color, motion, identity, etc. The visual tasks may include: visual inspection, face recognition, surveillance and monitoring, automatic target recognition, robot navigation, etc. Currently popular textbooks in computer vision include [3], [6], [5], [4].

This paper describes the experience gained with NSF-funded REU projects over the last 14 years. One hundred thirty undergraduate students from several institutions in Florida and outside Florida, and six faculty members (five from Florida institutions and one from out of state) have participated in our REU projects. This extensive experience has helped to focus our ideas of what traits lead to a successful experience.

A. Project Details

This project was started by M. Shah as the sole principal investigator in 1987, during his first year as an Assistant Professor. In fact, the REU grant was the first grant he received. During the first year, four students from UCF and three students from other nearby undergraduate institutions (Florida Institute of Technology, Melbourne; Stetson University, DeLand; and Rollins College, Winter Park) participated in this program. During 1989 to 1990, two other faculty members: K. Bowyer from the University of South Florida, and K. Ganapathi from Stetson University also joined the project. Undergraduates from all three institutions (UCF, USF, Stetson) participated in the program. All three universities contributed matching funds to the project in terms of additional student support, equipment, and travel, but not for faculty salary. The project continued with the same mix of faculty and students for 1990 to 1991 and 1991 to 1992, with similar matching commitments. At the end of 1991 to 1992 Krishnan Ganapathi from Stetson University decided to not to continue, and a year after that he left academia and started working in a private company. During 1992 to 1993 and 1993 to 1994 the first and the second author continued the project, with students from four institutions (UCF, USF, Stetson, and FAMU), and with similar matching commitments. During the next three years (1995 to 1998) two new faculty, Louise Stark from the University of Pacific (California) and Niels Lobo (from UCF) joined the project. Similar matching commitments from all three Universities continued. Students from four institutions (UCF, USF, UoP, Stetson) participated. At the end of this three-year project, K. Bowyer dropped out of participation due to difficulty in getting matching commitments from his University. The faculty from UoP also decided not to continue. During 1999 to 2001, all three faculty (M. Shah, N. Lobo, and A. Week) were from UCF. However, undergraduates from out-of-state universities (Fairfield University, NYU, Michigan, South Dakota, Illinois, Georgia Tech and Wisconsin-Stout, Yale, Wisconsin-Madison) in addition to students from UCF participated. During these three years, the first author received one-month

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summer salary as a part of matching commitment from his University, in addition to other support.

II. General Philosophy

The best way to achieve the goal of the REU program is to involve the students as a part of a successful, active research group. This involvement exposes them to the intellectual excitement of research, encourages them to think creatively and independently, and helps them to develop the skills necessary to work on research projects. In addition, students are exposed to professional meetings, learn to assimilate the latest research from reading and discussing research papers, and learn how to write and present the results of their own research.

It is obvious that an undergraduate research experience that lasts only a few months does not allow sufficient time to complete a serious project. Hence, such a short project would not allow participants the chance to achieve the feeling that they have made a significant original contribution. Since this feeling of accomplishment is the primary motivation of most researchers, the REU experience must be structured so that each student has the maximum opportunity to successfully complete their chosen project. Hence, our REU experience is spread out over (at least) one calendar year, typically as a summer/fall/spring sequence.

Interaction among students from different institutions greatly increases the diversity of ideas and the quality of the experience. During the academic year, however, guidance and supervision is difficult if the student and the faculty member are at different institutions. Consequently, it is important to have a faculty member at each institution directly involved with, and responsible for, each student. The faculty member can then more easily supervise the student's academic year course load and be available for advice and guidance. This management strategy has proven successful over the past 14 years.

A proper follow-through of students after completion of the REU experience is also crucial to their success. Therefore, students are guided to apply to graduate schools, are encouraged to take the GRE exam early enough that they can take it a second time if desired, are advised about which schools have good programs in certain areas, and are encouraged to apply for graduate fellowships (NSF, NASA, etc.).

The key elements of our REU model are summarized in a tabular form in Fig. 1.

- Calendar year experience, to allow time to complete a substantial project.
- Assignment of a faculty advisor from his or her own school to each participant.
- Immersion of the participants in research.
- Follow through over the year.

Fig. 1. Key elements of our research experiences for undergraduates model.

III. Selection of Participants

Students who are juniors or seniors in the fall semester of each year, who have a GPA of at least 3.25, and who have a strong background in mathematics and basic computer science are targeted for this program. A certain level of mathematics background is required to read many research articles. And a certain level of programming skill is needed to implement computer vision algorithms. After an initial screening based on written applications, the faculty members meet individually with the potential participants and decide who should receive offers.

A "word of mouth" from current and past participants is the most effective recruiting tool. In several cases, a participant in one year recommended a friend to us for the next year's program. However, to ensure that a broad cross section of students know about the program, the following efforts at advertising are also made by:

1) placing notices of the opportunity in the campus newspapers,
2) posting notices at various places on the campuses,
3) making announcements in the junior-level classes,
4) distributing announcements in Tau Beta Pi (Engineering honor society), UPE (Computer Science honor society), IEEE, and ACM student chapters,
5) sending letters to juniors majoring with a GPA of 3.25 inviting them to apply,
6) contacting and encouraging students in the Honors programs to apply,
7) asking current REU participants to give talks about their REU experience at SWE (Society of Women Engineers) and SME (Society of Minority Engineers) meetings in the spring semester, and at Faculty/Student Seminars, and
8) personally contacting and encouraging women, minority, and especially talented students to apply.

In the earlier years of our experience, about twice as many applications were received as the number of students that could be selected to participate. However, that ratio has dropped significantly in recent years. This drop is, at least in part, a result of the strong employment opportunities that exist for computer science majors. It is also certainly due, in part, to the level of financial support available to students through the REU program. The students who are not selected to participate typically either (1) do not have enough background in mathematics and programming, or (2) are unable for academic and/or financial reasons to devote substantial time in the summer to the REU program. The reality is that many talented and deserving students cannot afford to participate in the REU program given the level of the stipend. They simply have to make more money over the summer, and/or through part-time work during the year, in order to stay in school.

IV. Student Activities

One of the important goals of this experience is sparking the student's interest in scientific research as early as possible through interaction with faculty and other students. At the same time, each student must have sufficient time to mull over problems and somewhat independently achieve a reasonable level of solution of a problem of his or her own choosing. Students are able to devote a major portion of their time to the project during the summer, since they are not involved in regular courses. During the academic year, continued

student involvement is ensured by the faculty member at each institution. The professor(s) at each institution supervise the students through their registration in relevant elective courses and through weekly individual and research group meetings.

The experience has shown that there is often a need for flexibility to deviate from the "standard" one-calendar-year experience. Sometimes an excellent prospective participant has an academic or co-op schedule which does not allow a continuous 12-month participation. Sometimes, also, one of the participants does excellent work on his/her topic and does not graduate for as much as another year after the end of the 12-month REU schedule. In these cases, it is useful to offer the students a chance to stretch their "REU year" to some longer period. Last, a participant may be forced, due to personal reasons, to drop out of the program. Regularly about three such special cases occur out of ten participants.

The student activities are summarized in a tabular form in Fig. 2, and are discussed in detail in the following sections.

Activity	Frequency	Dates
Computer Vision Short Course	One full day a week	June 1–July 15
Ethics and Computing	Six lectures	June 1–July 15
Research Project		
Initial project selection	-	July 15-August 15
Presentation and revision of project	-	August 15-August 30
Research work on Project	-	Academic Year
Final report or paper	-	At end of academic year
Student-faculty Interaction		
Individual Meetings	Weekly	Whole Year
Research Group Meetings	Weekly	Whole Year
REU Group Meetings	Once a semester	Whole Year
Journal Club	4-6	Spring Semester
REU Speaker Series	2	Fall and Spring
Participation in Professional Meetings	one	Variable
Follow-Through	-	At the end of year

Fig. 2. REU student activities through the year.

A. Computer Vision Short Course

The first major activity for the students is the short course in Computer Vision. Since it is assumed that the students do not have prior background in Computer Vision, this course quickly introduces them to the subject. The topics covered include: imaging geometry, edge detection, region segmentation, 2-D shape, stereo and shape from shading, motion, etc. While some of the same core topics are covered every year, some topics also change from year to year based on the current emphasis within the research groups. The lecture component of this course is a one-day meeting each week for six weeks. During the remainder of each week, the students are assigned some readings in the area covered by the lecture material and are given one or two short programming projects which support the material. In the first two weeks, some extra instruction is given in C programming, X windows, and use of the Unix workstation.

B. Ethics and Computing

In addition to Computer Vision, lectures are also given on ethics and computing. The material is taken from the book *Ethics and Computing*, by Bowyer [2]. The topics covered in this part include: Professional Codes of Ethics, Intellectual Property, Ethics in Research, Whistle-blowing, Safety-Critical Systems, Hacking, Security, and Privacy. The topics are covered through a mixture of reading about the general concepts and analysis of specific case studies.

C. Student-Faculty Interaction

The appropriate level of student-faculty interaction and supervision of the participants is achieved by the following means:

Weekly Individual Meetings: Each faculty member holds a weekly individual meeting with each of their REU participants to discuss their research project.

Weekly Research Group Meetings: Each faculty member holds a weekly seminar-style meeting with his research group, in which current research papers are discussed, upcoming presentations by group members are rehearsed and discussed, papers by group members are "pre-reviewed," participants give presentations on the status of their project, etc.

REU Group Meetings: The whole REU group, consisting of faculty and REU students, meets once a semester. This meeting lasts for one day and is scheduled on weekends. The meeting is structured into presentation, demonstration, and discussion sessions. During the first session the students present their projects. These presentations include a brief introduction of the problem, results to date, and future plans. Next, the students are able to demonstrate their projects in the Computer Vision lab. Finally, there is an open discussion session where each student is encouraged to comment on other projects.

Electronic Mail: Students are able to communicate with fellow students, the graduate research assistant, and faculty at their campuses, as well as at other campuses, using electronic mail.

D. Journal Club

REU participants should also be exposed to other research problems in Computer Vision, beyond their own area of concentration. In order to achieve this exposure, a paper discussion session during the spring semester is organized. By the start of the spring semester, students have a fairly good idea of basic concepts in computer vision. Each time a research paper is selected and assigned to a student. That student studies the paper carefully and presents it in the journal club. The other students also read the paper and prepare questions and comments for discussion with the student responsible for that meeting. That way students will follow the content in the paper, and will also be trained to be critical in a constructive sense. These sessions are moderated by the faculty. Journal Club is an effective means of getting students accustomed to making presentations about technical material and learning how to read and comprehend journal papers.

E. REU Speaker Series

The aim of this series is to allow the REU participants to meet and interact with some well-known researchers in the field. Typically, during the morning the speaker gives a colloquium presentation. Usually, there is a lunch or dinner for the speaker, to which the whole group of REU participants is invited. Finally, in the afternoon an informal discussion session is held where the REU participants are free to ask questions related to any topic in computer vision. An attempt is made to schedule at least two guest speakers every year. The speakers who have been invited in the past include Sandy Pentland (MIT), Allen Hanson (UMass), Chuck Dyer (Wisconsin), Jake Aggarwal (Texas), etc.

F. Participation in Professional Meetings

Attendance at professional meetings gives the REU participants exposure to the well-known researchers in the field, provides an opportunity to see good and not-so-good research presentations, and provides an opportunity to assimilate the latest research results. Therefore, REU participants are taken to at least one professional meeting related to computer vision. Our geographic location often makes this possible at a reasonable cost. For instance, in 1994 and 1996 the IEEE Workshop on Applications of Computer Vision was held in Sarasota, and in 1995 the IEEE Workshop on Computer Vision was held in Miami. Sometimes the students are also taken to a conference outside Florida; for example, REU students were taken to ICCV'95 in Boston. REU students who get papers accepted in conferences often attend those conferences with travel funds from the grant.

G. Student Preparation and Follow-Through

Students receive background preparation for their research project through the computer vision short course in the summer. All students devote a substantial portion of their time during the academic year to the research project, since they have an independent study, senior project, or senior thesis supervised by one of the faculty. The students are helped as they apply for graduate school admission during the academic year. They are encouraged to take the GRE's early enough so that they can take them again if they do not do well initially. (It has been noticed that students taking the exam a second time often improve their scores by more than 100 points.) They are advised about which schools have good programs in which sub-areas. The qualified students are also encouraged to apply for graduate fellowships awarded by NSF, NASA, ONR, AFOSR, the Florida Endowment Fund program, and the State of Florida. Interaction with outside researchers visiting any of the campuses during the academic year is facilitated, so that students develop the contacts necessary for admission to the best schools. Company representatives are contacted, and interviews and site visits for students interested in industry are arranged.

V. Student Success

Approximately 130 undergraduate students from several institutions have participated in this program (http://www.cs.ucf.edu/~vision/reu-web/REU.html, a list of REU participants, papers coauthored by REU participants, and a sample REU proposal). These undergraduates have coauthored approximately 50 research papers; approximately half of these participants have gone to graduate schools; five students have written Honors in the Major Theses[1] three participants are now faculty members; and three participants have started their own companies.

- A 1999–2000 participant, Andrew Wu (University of Illinois), a 19-year-old freshman, worked on the "Virtual 3-D blackboard" project, and came up with a very novel method for generating 3-D trajectories of a finger using a single camera. He summarized his work in a research paper, which was accepted in the International Conference on Face and Gesture Recognition, held in Grenoble, France, in March 2000 [7]. The acceptance rate for this conference was 50%. Not a bad result for a 19-year-old student competing with senior researchers!
- A 1997–1998 participant, Doug Ayers (University of Central Florida) worked on "Monitoring Human Behavior in an Office Environment" for his REU project. His paper was accepted in IEEE Workshop on Applications of Computer Vision, 1998 [1]. The extended version of his paper has been accepted in *Image and Vision Computing* journal for publication. Doug completed his Honors in The Major Thesis in April 1998. He spent summer of 1998 as an intern at Harris Corporation. He was admitted to the graduate program at University of Maryland, and completed his MS in 2000. Currently he is working at Science Applications International Corporation (SAIC).
- A 1996–1997 participant, Sean Dougherty (University of South Florida) developed a method of empirical evaluation of edge detectors. The method uses hand-marked "ground truth," adaptive sampling of detector parameter space, and receiver-operating-characteristic curves. He published one book chapter and three conference papers.
- A 1993-1994 REU participant, Jim Davis, University of Central Florida, worked on *gesture recognition* for his REU project [8], [9]. A short version of the paper about Jim's work was accepted in the *1994 European Conference on Computer Vision* (acceptance rate 18%), and a long version appeared in a journal. He completed his Honors in The Major thesis in 1994. Jim was admitted to the graduate program at MIT with full fellowship for the Ph.D. degree. In summer of 2000, he completed his Ph.D., and started working as an Assistant Professor at the Ohio State University.
- A 1991-1992 REU student from USF, Adam Hoover, went on to complete his Ph.D. at the University of South Florida. He then worked as a post-Doc at the University of California at San Diego, and is currently on the faculty of Electrical and Computer Engineering at Clemson University.
- A 1991-1992 REU student from USF, Melanie Sutton, worked on "Reasoning about function to achieve generic recognition of rigid 3-D shapes." This project led to graduate work which was eventually published in the journal, *Pattern Recognition*, and received honorable

[1]Honors students can select to write Honors in The Major Thesis during their senior year to substitute for two to three regular courses.

mention for *Pattern Recognition*'s best paper of 1994 award [13]. Melanie is now on the faculty of Computer Science at the University of West Florida.

- A 1999–2000 participant, Paul Smith (University of Central Florida), worked on "Detecting Driver Alertness" project. His paper was accepted at the International Conference on Pattern Recognition, September 3–8, 2000. Paul received a Barry M. Goldwater Scholarship, a first award in UCF, on his REU project. He is currently working on his Ph.D. at UCF.
- A 1989-1990 REU participant, a USF student, Maha Sallam, had a paper describing her REU work accepted by the *Pattern Recognition Letters* journal and then had a paper describing her continued work accepted as a "long paper" at the *1990 International Conference on Computer Vision* (ICCV) (acceptance rate 5%) [12]. She completed her Ph.D. at USF and is one of the founders of a medical imaging start-up company in the Tampa Bay area (www.ismd.com, for more information on this company). Her company recently won an SBIR grant for approximately one million dollars.
- A 1987–1988 REU participant (University of Central Florida), Jay Hackett [10], [11], worked in the area of multi-sensor fusion, and his studies appeared in the *IEEE Conference on Robotics and Automation* and in the *Optical Engineering* journal. He successfully completed his M.S. at UCF. He now works for Harris corporation in Melbourne, Fl.

VI. Observations

Some of our strongest observations from 13 years of experience with the REU program are the following:

- The Department and University generally encourage this activity. Each year some matching funds from the University are received in terms of course release during the academic year, graduate student support, travel support, etc. The University newspaper has published at least four stories about REU, twice on the front page. In 1991, a luncheon at UCF in honor of the REU students was organized, with the university president and college dean in attendance. The REU program is considered positively in the tenure and promotion process, and in faculty evaluation for some other awards (e.g., Teaching Incentive Program). The REU program stands out from other standard activities of faculty, such as teaching, research, and service.
- The REU program is *very* time-consuming for the faculty member. In particular, summer is very hectic. The faculty need to spend almost the entire summer on campus, because this is a crucial time for getting the new REU students started. At the same time, the REU budget guidelines do not normally allow any faculty salary support. The budget guidelines also require a reduced indirect cost rate, and encourage matching funds. This imbalance between the true costs of the program and the allowed budget is perhaps the main drawback of the REU program. Effectively, the faculty member's time commitment to the REU project must be supported in some way by the institution. The current mood at many institutions is that externally supported projects must pay for all their real costs. This stand has caused Kevin Bowyer to drop out of participation in the REU program.
- There are always some students who are either discontinued or are dropped from the program. Some of these students find out that they are not really interested in research, and others find that financial concerns are playing a big role in their lives and that they can make more money at part-time jobs.
- There are two main deficiencies in the students' background relative to preparation for research in computer vision: mathematics and programming. In this connection, the students are directed to read and understand the selected research papers, the math, and implementation of algorithms.
- Summer is the crucial time, because during fall and spring students get very busy in their course work. If a student does well during the summer, has defined a good project, and has started to get some results, then he or she will generally do well during fall and spring. On the other hand, if the project is not well defined in the student's mind by the end of the summer, progress will be more difficult during the academic year.
- It has been noticed that some bright students are only interested in relatively superficial activities, or in short-term results. They are willing to write some code to experiment at a superficial level with an idea. But, when things get serious or the work becomes mathematical, they back off. Some of them will make comments like, "It is too early for me to commit to any particular area; maybe vision is not my area."
- Some students do not do that well during REU, but later they realize their potential, and become heavily interested in research, and go to graduate school. They always remember REU as a positive experience.
- During the last three to five years, it has been noticed that fewer students apply for the REU program than was the case five to ten years ago. This fact may be due to the easy availability of a large number of good-paying full and part-time jobs in programming.

VII. Conclusion

The National Science Foundation's "Research Experiences for Undergraduates" program has the very worthy and important goal of identifying and nurturing talented students to pursue graduate study and enter research-oriented careers. In this program much experience has been accumulated with approximately 130 students participating in the REU program over a 14-year period. Many students have published papers in the most competitive conferences and journals in the field. Many of these students have also gone on to successfully pursue a Ph.D. Thus it seems clear to us that the REU program as a national strategy is capable, at least in principle, of achieving its goals.

Perhaps the most satisfying element of the experience for the faculty member is that the REU experience was literally

life-changing for some students. Several students who had never seriously thought of going on to graduate school before they entered the REU program changed their life goals, entered graduate school, and became faculty members themselves. Perhaps the least satisfying element of the experience for the faculty member revolves around the budget constraints of the REU program. Substantial matching commitments are necessary from the university in order to make the program feasible. One of the biggest such elements is allocation of faculty time. Somewhat by definition, it is difficult for the REU program to succeed in an environment where there is no high-quality ongoing research. However, it is also difficult for the REU program to flourish in an environment where the primary task of the faculty member is to attract a large dollar volume of external research support.

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Mubarak Shah received the M.S. and Ph.D. degrees both in computer engineering from Wayne State University, Detroit, MI, in 1982 and 1986, respectively.

Since 1986, he has been with the University of Central Florida, Orlando, where he is currently a Professor of Computer Science, and the Director of Computer Vision lab. He has served as a Project Director for the national site for REU, Research Experience for Undergraduates in Computer Vision, funded by the National Science Foundation, for the last 14 years. He has published one book, *Motion-Based Recognition* (Boston, MA: Kluwer, 1997) and more than 70 research papers in refereed journals and conferences on topics including visual motion, gesture recognition, lipreading, edge and contour detection, multisensor fusion, shape from shading and stereo, and hardware algorithms for computer vision. He is an Associate Editor of IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE.

Dr. Shah received TOKTEN awards from UNDP in 1995, 1997, and 2000; Teaching Incentive Program award in 1995; IEEE Outstanding Engineering Educator Award in 1997; IEEE Distinguished Visitor Program award 1997–2000; and Harris Corporation Engineering Achievement Award in 1999. He is a series editor of International Book Series on *Video Computing* by Kluwer Academic Publishers, *Pattern Recognition*, and *Machine Vision and Applications* journals, and a guest editor of a special issue of *International Journal of Computer Vision* on *Video Computing*. He has served on the program committees and chaired sessions of several conferences.

Kevin Bowyer (S'77–M'80–SM'92–F'97) received the Ph.D. degree in computer science from Duke University, Durham, NC, in 1980.

He is currently a Professor in Computer Science and Engineering at the University of South Florida, Tampa. His current research interests are in the general areas of image understanding, pattern recognition, and medical image analysis. He served as Editor-In-Chief of the IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE from 1999 to 2000. He is author of the book *Ethics and Computing* (Piscataway, NJ: IEEE Press, 2001), coauthor with Louise Stark of the book *Generic Object Recognition Using Form and Function* (Singapore: World Scientific, 1996), coeditor with Narendra Ahuja, of the book Advances in Image Understanding (IEEE CS Press, 1996), coeditor with Sue Astley of State of the Art in Mammographic Image Analysis (Singapore: World Scientific, 1994), and coeditor with Jonathon Phillips of Empirical Evaluation Techniques in Computer Vision (Los Alamitos, CA: IEEE Computer Society Press, 1998).

Dr. Bowyer was the North American Editor of the *Image and Vision Computing Journal* from 1994 to 1998, and serves on the editorial boards of *Computer Vision and Image Understanding*, *Machine Vision and Applications*, and the *International Journal of Pattern Recognition and Artificial Intelligence*. He served as General Chair for the 1994 IEEE Computer Vision and Pattern Recognition conference and as chair of the IEEE Computer Society Technical Committee on Pattern Analysis and Machine Intelligence from 1995 to 1997. He received an Outstanding Undergraduate Teaching Award from the USF College of Engineering in 1991 and Teaching Incentive Program Awards in 1994 and in 1997.