Increasing Student Retention in Computer Science through Research Programs for Undergraduates

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1 Introduction

Publicity regarding the loss of IT jobs due to the bursting of the dot com bubble and the outsourcing of jobs from the US is frequently suggested as a reason for the drop in enrollments in post secondary computer science programs and the shrinking of the pipeline to graduate school in the US. Contradicting public belief in a tight IT job market, the US Department of Commerce [Sargent 2004] is projecting growth in the number of job openings for computer scientists through 2012 and researchers are now predicting a shortage of IT professionals in the USA over the next ten years [Lazowska 2005].

Figure 1: Clifford Manzanillo (URI CS student) inspects the Virtual Aquarium project at IMEDIA.

With the dependence the US economy has on innovation, a talent shortage will have broad economic impact in what is becoming an increasingly competitive global market. In 2005 the H1B visa quota was reached in record time, forcing companies to request that the US government extend the program. However for many industries dealing with US government projects, of special concern is the relatively small number of US citizens enrolling in computer science programs [Freeman and Cuny 2005]. Worse still as enrollments drop in the computing disciplines, the proportion of students who are female, minority or with disabilities remains a situation that is unacceptable [Freeman and Cuny 2005]. This argues for special attention for underrepresented groups as an essential part of a viable strategy for increasing college enrollments.

At the University of Rhode Island (URI) and IMEDIA in Providence, Rhode Island, we have for two years brought together local undergraduates from art, design and computer science majors to engage in a structured program of 3-D graphics and new media research. Our primary goals are to increase the number of students continuing to graduate studies in computing and continuing onto scientific careers, particularly in research. We are concentrating on students from groups who are underrepresented in computer science and who do not have access to a research program where they are studying. Even though some students in our program do not continue to graduate school, we believe we strengthen the overall retention rates in computing and train a stronger industrial workforce. The international competition in IT is increasingly strong, and we expect that these research experiences will help to provide a more competitive US IT workforce that is more creative, more effective when working in teams, able to work in interdisciplinary and cross-cultural projects, and capable of solving the computing problems of the next decades.

Our approach incorporates problem-based learning and extensive mentoring practices. Our focus is on interdisciplinary 3-D graphics and new media research with a strong influence from art and design. This interdisciplinary research experience has many benefits for students including learning to work in groups, learning the research process, and meeting a diverse set of researcher mentors. To meet this aim we provide formal training in teamwork, ethical practices, problem solving, technical writing and presentations, and outcome dissemination. The students who work at IMEDIA have the opportunity to participate in an international experience in Darmstadt, Germany, with one of the institutes of the INI-GraphicsNet (*http://www.ini-graphics.net*).

An integrative approach to problem solving is thought to more strongly attract and engage students from all demographic groups [Bourette 2005]. Research also indicates that women and minorities are more likely to continue in a scientific discipline if they are able to engage in the solution of problems that have a viable connection to society [Margolis and Fisher, 2002]. Therefore many of the research projects offered in our program are connected to pressing scientific problems that span several disciplines and impact society.

Problem-based learning, much like most research practice, begins with the introduction of a problem to solve and then teaches students the skills needed to solve the problem. Many institutions have adopted this approach for undergraduates; see for example, http://www.udel.edu/pbl/, University of Delaware, Sept 19, 1999, updated Sept 19, 2005. It is believed that through this approach, students learn to think instead of learning only by rote. Engaging students in research projects was previously thought to be premature and inconsistent with good pedagogy. However, the parallels between problem-based learning and research practice argue for the participation of undergraduates in the process.

We believe that the problem-driven and interdisciplinary approach of research is more likely to “kindle a fire” in youngsters who do not connect as easily to the computing discipline through traditional classroom based instruction. Beyond producing the potential researchers of the future, this program is expected to produce lifelong learners and problem solvers.

2 Program Structure

Our program is funded through the National Science Foundation (NSF) Computer, Information Science and Engineering (CISE) directorate's Research Experiences for Undergraduates (REU) program as a site award. The program differs from most other awards as we do not recruit students nationally for a summer experience. We recruit students from the region and they undertake the program over the summer and the fall semester. We believe that this gives students the opportunity to develop their research solutions in more depth, and provides more time for related research, and the dissemination of results. The students receive more sustained mentoring because they work with the researcher for a longer period and then typically remain in the same region of the country after finishing the program. A list of supported programs can be found at: *http://www.nsf.gov/crssprgm/reu/list_result.cfm?unitid=5049*).

Recruitment

The catchment area for students for this REU Site is designed to be the immediate region surrounding the state of Rhode Island. This is because Rhode Island has a concentration of schools that do not offer substantial research programs in computer science apart from the University of Rhode Island (URI) and Brown University, and it offers a number of art and design schools, the Rhode Island School of Design (RISD) being the most well known.

Recruitment of the students for the REU site was performed through contact people at each of the local universities and colleges including the University of Rhode Island (URI), Rhode Island College (RIC), Providence College (PC), Johnson and Wales University (JWU), the Community College of Rhode Island (CCRI) and the Rhode Island School of Design (RISD). The students were directed to the website of the REU program (*http://reu.imedia.edu*) where they could peruse the project descriptions and lodge an application.

The program is limited to US citizens and permanent residents. We also strongly encourage students from groups that are underrepresented in computer science and information technology. Preference is given to students who are studying at a school or college without a strong research background in computer science and in particular computer graphics.

Research Project

Upon acceptance into the program, each student was given their own research project to conduct as a part of a larger research endeavor. They were assigned a direct project leader who was a practicing scientist or researcher and who also served as a mentor for the student in addition to the primary investigators.

Each project was designed such that the student could take it through the complete research process including defining the problem and preparing a proposal with an estimated budget, peer reviewing the project proposals of their colleagues, implementing the project and preparing results, developing and delivering technical presentations on their work, and preparing technical publications such as reports, posters and papers. To assist the students in this process, a seminar series was developed in which seminars, discussions, and hands-on experience help provide them with the necessary knowledge, ideas and tools to complete the project and to develop worthwhile and tangible results.

Seminar Series

Seminar 1: A summary description of the overall research process and what constitutes scientific research. The process of reviewing related research and the literature, formulating the problem, inventing a reproducible solution, measuring the success of the approach and presenting the results are described. The key documents and presentation types that are created for each step are introduced.

Seminar 2: A review of the technical writing process. As well as presenting approaches and structures for technical writing at the sentence and paragraph level, the overall structural difference between various technical documents is discussed and examples are provided. Included in this list are technical proposals, literature reviews, papers for journal, conferences and workshops including posters, abstracts, short papers, technical papers, application papers, surveys, and tutorials. The approach of authoring for the audience is emphasized.

Seminar 3: The students were engaged in a group learning activity where they build and analyze the design parameters, characteristics and behavior of a spinning top. Various approaches to problem solving are explored and then discussed. The problem solving strategies range from highly structured to loosely structured and include hybrid techniques. After trying these approaches, students are asked to comment on the effectiveness of each for the top design and building exercise and then asked to think about how they might tailor the problem solving approach to different types of problems.

Seminar 4: A group discussion about teams, collaboration and mentoring. The roles of mentors and the differences to that of managers are discussed, as well as what the person being mentored should expect. A group activity placing the participants into the conflict between personal and group profit when collaborating on a task is undertaken.

Seminar 5: A group discussion on the reviewing process and an activity on how to present affective criticism. During the meeting the project proposals written by the students are submitted and assigned to various reviewers within the same group. The students then provide a review of their colleague's proposals. As well as discussing how to provide writing reviews and criticism, we also discuss how to provide affective verbal criticism. This is done through an initial preparatory presentation to the group about their work before the final public presentation. After the question time of the preparatory presentations, we include a discussion where we ask everybody to comment on the performance of the presenters, emphasizing their strengths and suggesting improvements.

Seminar 6: A presentation on presentations. Starting with an example of things you should never do in a public presentation to get the student's attention, we then discuss various types of presentations and their structure, good and bad habits of public speakers, the necessity of rehearsing, and understanding and speaking to your audience. Different techniques for organizing the presentation and presentation materials are provided.

Seminar 7: A discussion on ethics in scientific research and development is conducted. We concentrate on human subject research and use the material provided by the Internal Review Board of the University of Rhode Island as the basis for the discussion.

Seminar 8: A discussion on the considerations of working and researching in an international environment. Due to the broad base of national backgrounds and language groups of the students and staff involved in the program, we ask the participants to discuss their experience and expectations when working in multicultural groups. For example, the nine people involved in the 2004 seminar had experience of 13 different countries and seven different languages. The seminar was to prepare the four students at IMEDIA to travel to Germany for a month for their International Experience.

Presentations and Publications

A scientist's ability to communicate the results of their work is essential. Therefore the students were given the opportunity to present their work in both verbal and written technical form. Given that positive private experiences often provide a greater educational experience the first time, each of the students presented their project to the group first in a 20 minute technical seminar. The agenda for each presentation followed that which would be experienced by the student in a more public session. Their supervisor introduced them to the group, they presented their work with visual aids and provided a demonstration of their work. A ten minute question time followed the verbal presentation and they were thanked through applause for their effort. To support the student in improving their presentation a critique session was then undertaken with the premise that both positive and negative criticism be provided to strengthen what the student did well and to suggest how the presentations could be improved.

The preparatory presentations were to support the presentation of a ten minute final presentation that is public. Conducted in a two hour session at the end of the program, the final presentations has attracted faculty and researchers from all of the local colleges and universities up to the Dean level, as well as a number of local business and government representatives. The presentations are recorded and presented on the website (*http://reu.imedia.edu*).

To support the written publication of the student's work, the first step taken is to have the students present a poster abstract to the Consortium for Computing Sciences in Colleges — Northeastern Region (CCSCNE) conference. This allows the students to enter the realm of academic conferences with the support of their peers with the acknowledgment of external academics that this is their first foray into the field. From here several students have gone on to present their work at international conferences and to assist in writing other technical papers and articles (see examples in Section 5).

International Experience

The students who undertake their research experience at IMEDIA also have the opportunity for participating in a month long international research experience in one of the research institutions of the INI-GraphicsNet (*http://www.ini-graphics.net*). Each of the four students in the past two programs have spent four weeks at the Fraunhofer Institute for Computer Graphics (IGD) (*http://www.igd.fhg.de*) or the Center for Computer Graphics (ZGDV) (*http://www.zgdv.de*).

The students either joined an ongoing research project at the host institution or continued their own research project under the supervision of a local supervisor. They were given access to all of the different research groups at IGD and ZGDV and encouraged to discuss their research with the others researchers.

3 Project Examples

The projects that have been offered include:

- Volumetric reconstruction and visualization of a rat brain
- Protein visualization
- Studying the use of illustrative rendering techniques for visualization of information quality and criticality
- Implementing a ray-based volume rendering system in a CAVE environment based on a PC cluster
- Visualizing the deformation of articular cartilage in the human knee
- Using laser pointers to interact with project media
- Dual coding theory for the teaching of computer science concepts in interactive and classroom environments
- Interactive network security monitor

We showcase two projects that have hosted a number of REU students over the past two years, the Interactive Aquarium project at IMEDIA and the Pedestrian Evacuation project at the URI.

Interactive Aquarium

Modern science museums use highly interactive exhibits to engage their visitors. However, other informal education centers such as zoos and aquaria suffer from the problem that direct interaction with their specimens is undesirable. While the interest of visitors in interacting with living creatures is evident by the popularity of touch-tanks and petting-pens, visitors must be protected from the specimens, and specimens from the visitors. The Interactive Aquarium project [Stephenson et al. 2005] explores novel edutainment approaches for promoting interactivity and cognitive elaboration in the public setting.

Figure 2: An example configuration of the Interactive Aquarium systems showing all three components. Towards the back is the Virtual Aquarium, to the left the stationary interaction and being held, the mobile interaction panel.

The Interactive Aquarium system includes three components: the Virtual Aquarium, Dynamic Interaction Panel, and Mobile Interaction Panel (c.f. Figure 2). By combining these components, various educational strategies can be realized. (1) A virtual environment in which a real aquarium can be replaced by a virtual aquarium for story telling purposes. (2) An information system that is interactive, dynamic, personalized, and maintainable. (3) A technique in which natural urges to point and touch things of interest is supported to retrieve information about specimens in the aquarium. (4) An integrated map and exhibition guide that is personalized. (5) An activity system that can be used to tie together concepts and processes across an entire exhibition. (6) A novel educational approach to promote better memorization of facts and constructional knowledge evolvement.

The Interactive Aquarium: Personalizing the Visitor Experience

Sara Czyzewicz
Bachelor of Arts (Computer Science)
Rhode Island College

Each day more than 2.3 million people visit museums in the USA: People of differing ages, education levels, motivation, interests, physical abilities and cultural backgrounds. To support the diversity of visitors, Sara developed a system for personalizing the content and interface of the Interactive Aquarium information systems to provide the opportunity to present information according to each individual's needs and wants. Features of the personalization include various levels of detail and sophistication; in various languages such as English, Spanish, and German; with visual adjustments of text size; customizable topics of interest; and personalized information collection management. Sara developed an XML schema to populate the Flash-based interface using various language-based data files (c.f. Figure 3). Therefore expanding the content is a simple task.

Figure 3: The personalized interface of the Interactive Aquarium information system.

The Interactive Aquarium: Game-based Interfaces

Stephen Lecrenski
Bachelor of Science (Computer Science and Finance)
Providence College

Public aquaria have a difficult problem in producing live deep-sea exhibitions due to the challenges in maintaining the extreme environment found at 4,000 meters beneath the sea surface. Deep-sea creatures cannot exist at surface pressures due to their unique anatomy; therefore exhibits typically comprise preserved specimens with supporting information. This limits the educational experience that can be achieved. Visitors cannot experience the behavior of the creatures, even how the creatures move, or the interaction that occurs between creatures and their environment.

To offer an exhibit in which visitors can explore the deep sea, Stephen created an immersive game-based virtual environment in which visitors navigate around a hydrothermal vent seeking out the special creatures and geological structures that exist there. The creatures that can be discovered are tubeworms, anglerfish, fang tooth fish, deep-sea crabs and vampire squids, which were animated based on actual video footage. To retrieve information about any creature or geological feature, the visitor just has to touch the specimen on the screen.

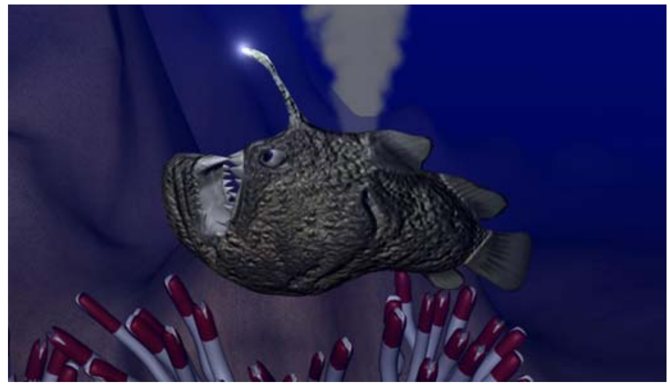

Figure 4: The Anglerfish from DeepSea displayed in front of the hydrothermal vent and above a bed of tubeworms.

Evacuation Project

The pedestrian evacuation project is a multidisciplinary project to analyze and simulate the group behavior of pedestrians involved in normal (non-emergency) and evacuation (emergency) activities [Peckham et al. 2005]. The aim of the project is to help engineers and architects design safer buildings and evaluate existing buildings by developing a micro-simulation tool for pedestrian flow dynamics. The tool utilizes three-dimensional models of the pedestrians and the surroundings, simulates pedestrian evacuation behavior, and thus pinpoints evacuation flow bottlenecks, and predicts the average and maximum evacuation times, the pedestrian volume to evacuate over time, and the completion times of normal pedestrian movement.

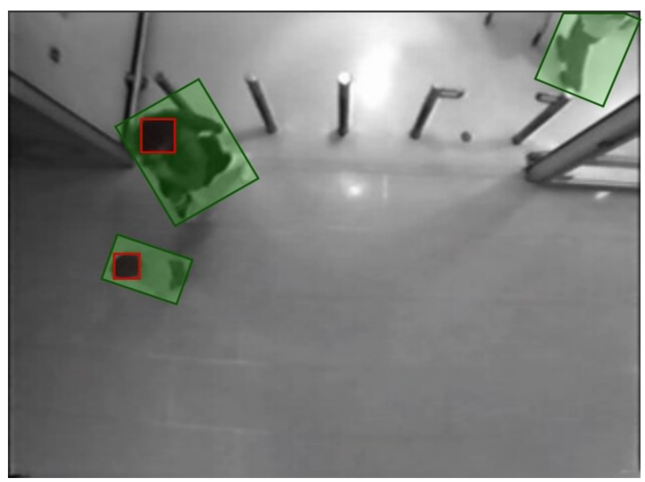

Figure 5: Tracking software used to authenticate the simulation of pedestrian evacuations.

The disciplines involved in the research include computer science, civil engineering, industrial engineering, behavioral psychology, and social psychology. The test beds for the project are the Providence T.F. Green airport and two concert halls on the URI campus.

Behavior-based Simulation of Pedestrian Movements
Elizete Fernandes
Bachelor of Science (Computer Engineering)
University of Rhode Island

Elizete's project was the development and implementation in Java of a behavioral model of pedestrians engaged in normal and emergency activities. Her role in the design phase was primarily to bring in the point of view of the software designer such that the various elements of the model discussed map well to software modules, classes, and objects. The behavioral model distinguishes the high-level planning of an agenda, which consists on the ordering of a number of objectives, from the low-level planning of a trajectory from the current location to a destination that corresponds to the completion of the current objective.

Development of a Library of 3D Models of Humans
Katharine Wray
Bachelor of Fine Arts (Industrial Design)
Rhode Island School of Design

People come in all sorts of shapes and sizes. To ease the process of producing various three-dimensional models of pedestrians, a parametrically defined model was constructed. Katharine built a library of basic body types that considered characteristics such as gender, age (toddler, child, teenager, adult, elderly), height (short, normal, tall), girth (thin, average, fat, obese), etc. If the simulator calls for a “short, thin female child,” the interactive visualization module of the pedestrian project would select an instance of such a body type from the library. The model was developed in Maya (c.f. Figure 6) and the results exported to the MD3 format.

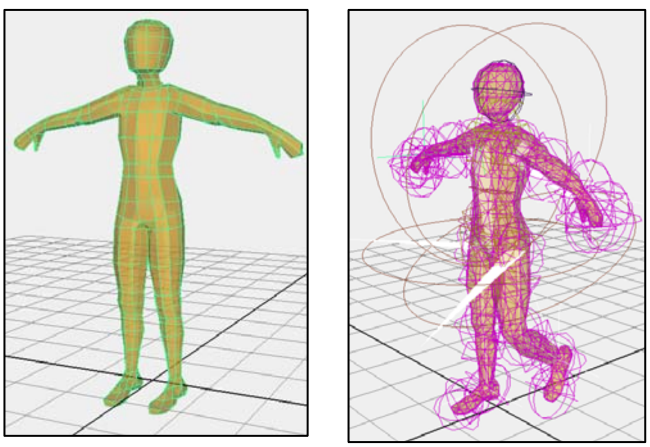

Figure 6: Parametric and kinematics models of a person developed for the evacuation project.

A 3D model of a human consists not only of the geometry (and texture, for clothes and skin) of the body, but also of the gestures of a human with these body characteristics undertaking various activities: walk, fast walk, run, jump, crawl, etc. Ideally, this kinematics information would be provided by a motion capture system. In this first version of the library, Katie had to rely on the observation of video sequences taken at the Providence T.F. Green airport to build her kinematics model.

Interactive Visualization of Pedestrians in a Building
Angel Castro
Bachelor of Science (Computer Science)
University of Rhode Island

Angel's 3D visualization module required the chronology file produced by Elizete's behavior-based simulator and the human models created by Katharine. As a consequence, he assisted in the design of the behavioral model and in the definition for the specifications of the pedestrian chronology and of the human model library. He evaluated various solutions for the 3D visualization module such as Java3D, a C++ graphic library and various game engines. Angel final system automatically translated a pedestrian chronology file produced by the behavior-based simulator into a motion script for a “non-playing character” for visualization in the Unreal game engine.

4 Results

During the 2004 and 2005 programs there were a total of 17 participants, all of which completed the program. In the 2004 program there were three women and five men, of which three were from minority groups. In the 2005 program there were three women and six men with three students from minority groups.

To measure the experience of each student and their attitudes to scientific research, a survey was given to the participants when they joined the program, and another similar questionnaire was administered on completion.

The questions asked were:

1. ***Do you plan to get a graduate research degree?***
2. ***Do you plan to do research in an industrial setting?***
3. ***Indicate your overall impression of your research experience.***
4. ***Rate how likely you would be to participate in another research experience if you were given the opportunity.***

The responses collected were based on a Likert type scale in each case, for example: Strongly disagree (0), Disagree (1), No opinion (2), Agree (3), Strongly agree (4). Table 1 reports the mean response to each of five questions about learning for both the entrance and exit questionnaires for all 17 participants in both completed programs. While we achieved a 100% retention rate and even extended the program for some students upon request, some did not return their exit surveys.

	2004		**2005**		**Overall**	
Question	**Entry**	**Exit**	**Entry**	**Exit**	**Entry**	**Exit**
Responses	8	4	9	5	17	9
1.	1.25	2.00	1.78	1.40	1.53	1.67
2.	1.00	1.38	1.22	0.80	1.12	1.06
3.		3.75		3.40		3.56
4.		3.88		3.20		3.50

Table 1: Summary of responses to the entry and exit survey of the students.

In addition to these quantifiable data, open-ended qualitative questions were asked on the follow-up questionnaire. Given below are the questions and a summary of what was mentioned in the responses for the 2004 and 2005 programs with the number of responses mentioning these aspects in braces:

What did you like most about the research experience?

1. The people the students worked with (6 response in total): the mentors and project leaders (3), the other students (1), and programming teams (2)
2. What was learnt (5 responses in total): General (1), programming (1), writing (2), 3D modeling (1)
3. Exposure to teamwork (3)
4. The projects (3)
5. Food supplied at meetings (2)
6. Feeling of achievement (2)
7. Working environment (1)
8. Exposure to research (1)
9. Understanding what graduate school will be like (1)
10. International experience (1)

What did you like least about the research experience?

1. Meeting (3 responses in total): Too many meetings (3), the commute to meeting (2)
2. No set workplace (1)
3. Lack of time to present in final presentation (1)
4. Project not focused on major (1)

Recommend changes that we should make to the program to provide a better experience for undergraduates.

1. Reduce meetings (3): Regularity (2), length (1)
2. Supply a workplace (1)
3. Provide more direction in research (1)
4. I really enjoyed the entire experience (1)
5. *Let students know that as a Computer Scientist, knowing how to research correctly will help us, especially when working with new technology* (1)

Describe how your participation in this research experience changed your views about research.

For this question we leave the individual answers.

1. *Has shown me the intricacies of research. There are way more rules and guidelines to conducting research than I thought.*
2. *I informed myself about other people's project[s]. Got more information about people[‘s] behavior.*
3. *I never realized how interesting research can be, especially when researching a "new" topic. It can be real exciting to be using state of the art technology.*
4. *Research can be done on a variety of topics, Not as bad as it sounds.*
5. *Research is much more design/development oriented rather than solely gathering data.*
6. *I have realized that research is considerably more difficult than I imagined, but that I enjoy it.*

Of the 2004 group, three students have enrolled in postgraduate research degree in science, two have continued in postgraduate technical training, and three have entered the scientific work force.

In addition to providing students with a positive educational experience in a research environment and improving retention rates to postgraduate studies and the scientific workforce, another metric for success prescribed by the NSF is the level of publication of research results involving the REU students. Of the 2004 group, each student presented their own posters at the Consortium for Computing Sciences in Colleges — Northeastern Region (CCSCNE) conference. A poster based on Katherine Wray’s work on Information Visualization was also presented at the R&D Partnerships for Homeland Security conference.

Technical paper presentations were given by Sara Czyzewicz [Czyzewicz et al. 2005] and Stephen Lecrenski [Lecrenski and Stephenson 2005] at the Training, Education and Simulation International conference (TESI 2005) in Maastricht, the Netherlands. Both students also helped co-author a paper for the SIGGRAPH Educators Forum in 2005 [Stephenson et al. 2005]. Angel Castro, Elizete Fernandes and Katherine Wray helped co-author a paper for the International Conference on Computing in Civil Engineering [Peckham et al. 2005]. Peter Firth assisted in publishing an extended abstract at the International Conference on Human-Computer Interaction (CHI 2005) [Branco et al. 2005].

While the 2005 group have just completed the program and are now preparing their papers for submission, each student has again had posters accepted to the CCSCNE 2006 conference. We hope as we found last year that having the entire group presenting their results at such a conference is an inviting, well supported and very positive introduction to presenting at academic conferences.

5 Discussion

To address the alarming decrease in students and the under representation of women and minorities in Rhode Island computer science programs, we have devised a program to introduce students to research in computer graphics, art and new media. This program integrates good mentoring practice and pedagogy, including problem-based learning. Special attention is paid to creating a cohort of students who come together every week to learn about the research process, and ethical and societal issues related to it. The students have performed beyond our initial expectations. They have been enthusiastic about the program and have continued beyond our program to pursue other computing research programs. In addition, most have disseminated their results by presenting posters and papers at conferences. We have also noticed that the program has also stimulated interest in computing among the participating art students, with one pursuing computing courses after finishing the REU program, and others securing employment in computing environments. The researchers involved in the program have also been positive about the experience. This program nicely integrates the important missions of teaching and research.

As is evidenced by the results of the surveys, there are some very special issues that need to be addressed with undergraduates. For example, in the surveys there are comments about students not having a set workplace. This was an anomalous situation at the URI site in the second summer due to laboratory renovations.

This caused the students to be somewhat more scattered in their hours and place for work. This is an era of pervasive “anywhere, anytime” computing practice. But with undergraduates embarking on their first research experience, we have found that it is very important for them to meet for business and fun purposes regularly, and to have regular work hours where they can carry out their research in the same location. Even if they are working on different projects, the presence of their colleagues and mentors seems to have a significant positive influence on their experience and leads to stronger research results.

Also of note was the students’ recognition after the program that research is a collaborative experience that requires good communication skills to carry out and disseminate the work. It is easy for faculty to expect that students are comfortable with the many facets of a computing professional, including the ability to work with others who are more experienced. Anecdotal evidence indicates that the fear of working with a cohort that is much older and experienced is a real fear for students exiting the university and entering graduate school and industry than would be expected. Thus the “face time” with faculty and graduate students is extremely important.

6 Acknowledgements

The project has been supported in part by the National Science Foundation (NSF) through the Research Experiences for Undergraduates (REU) program, grant number 0353786. The Building Evacuation project at the University of Rhode Island is supported by the NSF through grant number 0331984. The University of Rhode Island has partially supported the work of the students thorough the 3-D graphics partnership laboratory. Several projects at IMEDIA were partially sponsored by the Ocean State Technology Corporation through the CARUSO project, contract number OS-05-2221. We would like to thank the INI-GraphicsNet and specifically Fraunhofer IGD and ZGDV for supporting the International Experience for students in this program.

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