A Virtual Laboratory Model for Encouraging Undergraduate Research

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ABSTRACT

Undergraduate students who perform research benefit greatly from the experience, yet achieving high levels of voluntary participation remains an elusive goal. This paper describes the implementation of an innovative laboratory model designed to encourage computer science undergraduates to actively pursue collaborative research with faculty and other students. As an extension of earlier research into team-based software engineering education, the Applied Computing Technology Laboratory was formed to provide an authentic and engaging experience in real-world computer science research. The model, which relies on a web site as its focus, is presented along with the results of one year of active research.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: COMPUTER AND INFORMATION SCIENCE EDUCATION –*Computer science education*.

General Terms

Design, Experimentation, Management.

Keywords

Undergraduate research, collaborative learning, software engineering education, faculty-student research.

1. INTRODUCTION

Preparing undergraduates for life beyond graduation motivates many computer science programs to structure software engineering and capstone courses so that students are immersed in an industry-like experience. The exposure to common industry practices, business methods, and many of the real-world complexities inherent in an ambitious, team-based software project is valuable [4,5,9,10]. Providing students with authentic research experiences within the context of a course is difficult; research can involve literature reviews, planning, design, prototype system implementation, experimentation, and writing, all of which require a significant investment in effort over a relatively long period of time. Educators can limit the scope of research projects in order to introduce students to aspects of research, typically as part of courses in software engineering and capstone projects, an approach that has provided good results [6,8].

Offering research opportunities outside of the classroom is an attractive idea, although student participation hinges on making the experience more worthwhile than other activities on which students may spend their free time. Designing engaging research problems of an appropriate scope, providing independent study credit, and otherwise capturing the imagination of students is critical. A number of successful research programs have demonstrated that meaningful undergraduate research is an achievable goal [2,3,7], with a heavy emphasis placed on team-structure, formal research approaches and highly selective criteria for participation.

This paper presents an ambitious research laboratory model that builds upon the successes of these previous approaches. The result of this model is the Applied Computing Technology Laboratory (ACT Lab) which expands the idea of undergraduate research to create an environment inspired by such exciting and dynamic places as the MIT Media Lab (media.mit.edu) and Xerox PARC (parc.xerox.com). Upon joining the ACT Lab team, undergraduate students are encouraged to find innovative ways to use computing technology to solve any problem that catches their fancy. The ACT Lab is not a part of any class, and members need not be upper division or even computer science students, most of the current members came through software engineering and capstone projects classes taught with a company-based approach [10] that primed them for participation in research. The model is that of a "virtual laboratory" in that it requires no laboratory space of its own (yet), existing solely as a web site; when students need access to equipment, guidance or information, they invent ways to acquire what they need. Faculty members work with student researchers, when needed, offering advice, mentoring and hands-on collaboration. Students learn to do research by doing research, and they do it because it is their own.

Formed nearly one year ago, the ACT Lab is already producing intriguing software tools and a number of publishable results in a wide variety of areas. The model for the ACT Lab, including its organization, motivation and benefits, and a summary of a number of current projects, are the subjects of the remainder of this paper.

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2. VIRTUAL RESEARCH LAB MODEL

The virtual laboratory model is a structure for a flexible, efficient, and dynamic research program that encourages undergraduate research and collaboration with faculty, other students and industry. Using a web site as its principle manifestation, the model is designed to attract students of widely varying interests, which may not align with existing research projects. This is in contrast to the common practice of involving students in the current research of one or more faculty, which, while valuable, often requires a certain amount of academic maturity for full and active participation. With the virtual laboratory model, students gain entry into the world of research by pursuing a project that is particularly appealing to them.

If a student's initial research experiences are unappealing, boring or provide no feeling of incremental success, and lack a personal connection, the student is less likely to pursue research in the future. On the other hand, by engaging undergraduates in projects for which they feel a strong and personal affinity, they are more likely to be motivated to continue on into future research at the graduate level or at a university or industrial research laboratory.

The positive outcomes seen through use of a company-based approach to teaching software engineering courses, including an emphasis on brainstorming and entrepreneurship, provided the initial inspiration for this virtual laboratory model [10]. It is thanks to the energy and willingness of students from those courses, and a subsequent senior projects capstone course, that the ACT Lab exists at all. Students were so eager to continue working on their development or research projects beyond the end of the semester, that there was little choice but to create an outlet for this exploratory spirit. Interest from graduate students has been strong as well, with many pursing projects as part of independent study or individual enrichment.

2.1 Motivating Benefits

To motivate the design of this virtual laboratory model, and the subsequent implementation as the ACT Lab, the costs and benefits of such an approach were studied. Before the ACT Lab was formed, a significant amount of thoughtful analysis went into trying to answer the question, "Is this idea worth pursuing?" As a result, a list of potential benefits of this virtual research laboratory model was generated. The items from the list that were not too "out there" or "off-the-wall" (or just plain boring) are included here:

- Serves as a focal point for undergraduate research, providing an appealing image, drawing in students who might otherwise be reluctant to participate in research due to misperceptions.
- Fosters collaborative research among undergraduate and graduate students, faculty, and with outside industry and universities.
- Gives students a true stake in the outcome of the work beyond a mere grade, instilling a pride in ownership of both the problem and its solution.
- Costs no money, and only a small amount of time and a little familiarity with web design to start.
- Creates a flexible framework for organizing many and varied research and development projects under a single, cohesive program.
- Provides a platform for publicizing successes and sharing of ideas.
- Enables long-term thinking and planning, providing students with the opportunity to start long-range projects that they will pass on to future collaborating students.
- Provides a natural mechanism for distribution of completed software projects and research results.
- Reinforces lessons learned in software engineering courses, motivating practice in current approaches such as agile development and extreme programming on real-world projects.
- Creates opportunities for making connections in industry and with graduate programs at other institutions, opening the door to future career opportunities.
- Exposes students to the spirit of entrepreneurship and discovery of new ideas that is vital in the world of software business start-ups.
- Supplements course work with concrete application of the material gleaned from lecture, homework assignments and other classroom experiences.
- Teaches students to be self-reliant and proactive, develops an innate sense of urgency, and enables them to build valuable research skills that are applicable to future careers in graduate school, teaching and industry.
- Leads to publications for all involved, with a key outcome being that of helping undergraduates collect credentials for entry into graduate school or industry research jobs.

As the ACT Lab continues to evolve over time, no doubt many other benefits will appear, just as some of these may vanish. The unpredictable path ahead of the ACT Lab, as a recursive metaphor for research itself, seems to be an inescapable notion.

2.2 Organization

"*Simplicity is the ultimate sophistication.*" Leonardo da Vinci

The ACT Lab was purposely organized in a very simple and malleable way. The only preconditions for organization were a sincere willingness to encourage undergraduate research, a place to post a web site, and the comfort that comes from being entirely unsure if the idea will work at all. The key ingredients in the organization are the position of Director of Research, and an appealing, well-structured web site. The Director should be energetic, open, easy-to-talk-to, and a magnet for students interested in research (even if those students are unsure of their interest at first). The lab is organized into a number of independent, though occasionally overlapping, research groups. The focus of each group is entirely dependent upon the sorts of projects ACT Lab members dream up, so from year to year, it is quite likely that the collection of groups will change. The current organization of the ACT Lab is shown in Figure 1, including the research groups and selected examples of current projects.

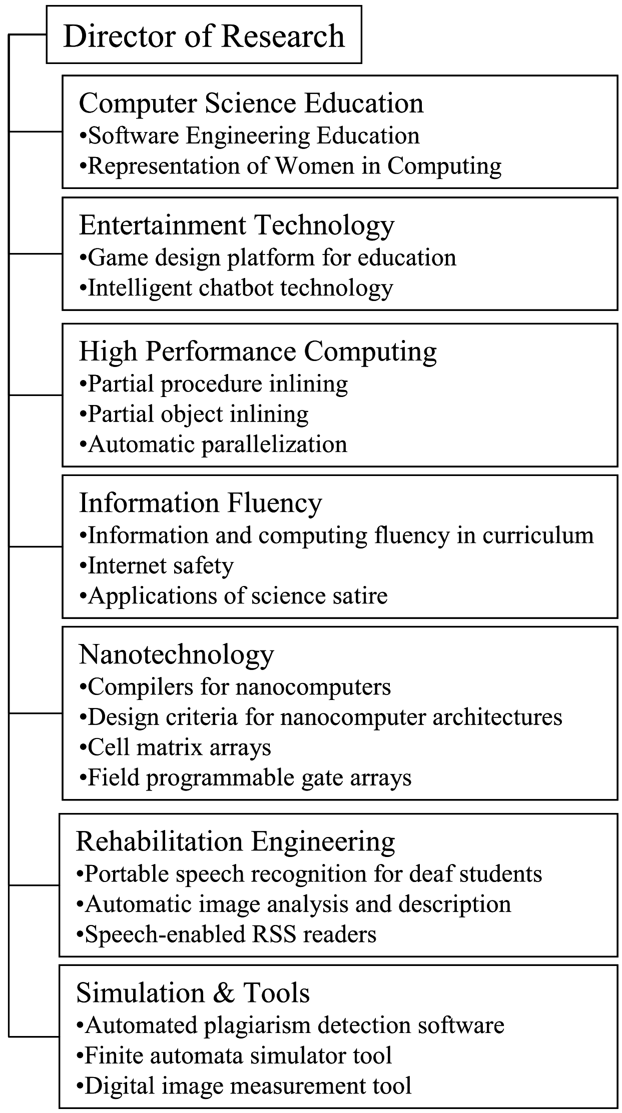

Figure 1. Organization of ACT Lab research groups.

The web site provides a focus for each of the research groups, with individual pages for each group to post any amount of information about their research [1]. Typically, general descriptions are provided, and sometimes extensive collections of links to online resources, such as related research projects, publications, conferences and products. Some groups include specific research plans and goals, communicating these via the web site, while others prefer to keep the online information minimal.

Other important features of the web site are pages for listing publications, downloads, general resources, members and information about joining the lab. The directory of members, which is invariably out of date as soon as it is uploaded, lists some faculty (some remain in the background), undergraduate and graduate students, and any other interested parties, including those who have agreed to collaboration at some unspecified time in the future. Aside from project descriptions, the membership directory has been one of the strongest recruiting tools; students see that a student they know and respect is involved, so they decide to join as well.

The most valuable feature on the web site is the Idea Incubator page, a place where the best and worst of new ideas are posted. Some ideas are clearly worth pursuing, while others are obviously worthless. However, it is often true, and has been the case with the ACT Lab already, that the "worthless" ideas have indirectly led to more interesting research contributions than the ideas that were "better"; thus are the vagaries of research.

3. PROJECTS

"*The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' but 'That's funny…'*" Isaac Asimov

For a project to be pursued by ACT Lab members, the most important characteristic is that it must be exciting to the students involved. Some non-repeatable combination of deep thought, brainstorming, and happenstance has led to the discovery of all of the project ideas being developed. Each of the ACT Lab projects has a goal to solve a particularly interesting problem, one that is hopefully worth solving, and which requires some exploration and research to discover or invent the solution. In contrast to this applied research approach, other projects involve more basic research with the goals being incremental improvements to an evolving body of knowledge and understanding. The current projects include:

3.1 Nanocomputer Design

In the emerging science of Nanotechnology, the attention of six students (three are graduate students) has been captured. With an overarching goal of producing a research compiler that will generate an optimal, customized nanocomputer from a source program, each student is performing research in a complementary area. The subprojects include: (1) automatic parallelization of source programs to make use of parallel architectures (2) design issues of parallel nanocomputer architectures, (3) application of FPGA and cell matrix array technology to nanocomputers, and (4) simulation of nanoscale logic gates and circuits. Not coincidentally, this most active of all ACT Lab projects falls within the primary area of research of the Director of Research (and author of this paper). The results of this research include some significant additions to knowledge in these areas, and a number of conference and journal articles in submission or preparation.

3.2 Speech Recognition for Deaf Students

One hard-of-hearing student discovered that ongoing advances in continuous speech recognition make it possible to use a computer to help deaf and hard-of-hearing students with note taking in class. The student acquired a wireless microphone, and enlisted the help of a professor to train the speech recognition software to recognize his voice. Experiments are underway to measure the effectiveness of using a laptop in class, connected to the wireless microphone, to capture in real-time the entire spoken content of the lecture. This is a new use of speech recognition, which has previously been focused on enabling computer users to control their machine with voice commands and to dictate short documents, subject to interactive voice-controlled editing.

3.3 Finite Automata Simulator

As a tutor to fellow students, one undergraduate noticed that others had a very difficult time grasping the various concepts of finite automata taught in a theory of computation course. What the students seemed to be lacking was a way to visualize an automata in action. Drawings and PowerPoint slide animations simply did not convey the ideas in an understandable fashion. The software available online was either no longer available, or was too sophisticated for these students. The solution was to design and develop educational software called jFAST (Java Finite Automata Simulation Tool) in the form of a Java-based program that enables students and teachers to design a variety of finite automata using a drag-and-drop interface and then interactively simulate the automata to gain a deeper understanding (Figure 2). By keeping the design simple, and removing any tendency to include idiosyncratic terminology or complicated commands, students and educators have found that jFAST, which will soon be freely downloadable, is very helpful in learning about finite automata.

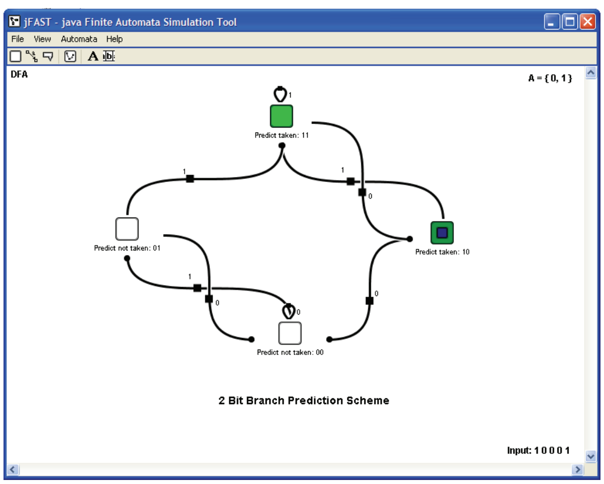

Figure 2. The jFAST finite automata simulation tool.

3.4 Digital Image Measurement Tool

With the widespread use of digital photography, and the inclusion of a significant amount of information about the image contained inside the header of image files, a student devised a technique for measuring distances within digital images. This project was developed in Java, and makes use of the information tags stored in an extended header of JPEG image files and the latest image manipulation and processing support in Java. Interest in the tool has been expressed by architects and crime scene detectives, each of whom could benefit from being able to make accurate measurements within a digital image. Significant development remains to be done, with the goal being the development of a commercial-quality tool.

3.5 Plagiarism Detection Software

Cut and paste plagiarism is a problem faced by educators at all levels due to the availability of vast amounts of easily copied material on the Internet. To combat cut and paste plagiarism, an automated software tool called SNITCH (Spotting and Neutralizing Internet Theft by Cheaters) has been developed (Figure 3). The program is written in Java, and makes use of the freely licensable Google Web Search API (google.com). The SNITCH program uses a plagiarism detection algorithm that analyzes a student paper, finding a number of potential instances of plagiarism based on word length and complexity, and then searches for verbatim matches via Google. SNITCH is designed to be a fast and free alternative to similar online services (e.g., TurnItIn) and commercial software (e.g., Eve2).

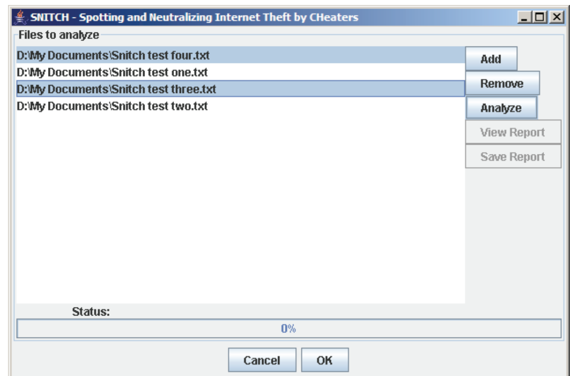

Figure 3. The SNITCH plagiarism detection tool.

3.6 Under-representation of Women in CS

In looking for a development or research project for the senior projects capstone course, a female minority student was drawn to the issue of under-representation of women in computer science and related fields. She designed and conducted an online survey, targeted specifically at women who were not lacking in opportunities in high school and college. The study is ongoing, and is trying to determine why, even when female students are provided with ample opportunities and encouragement to pursue studies and careers in computer science, do they continue to be underrepresented.

3.7 Automatic Image Description

The availability of 3D image capture equipment in ACT Lab's department has led to the very initial stages of a project that promises wide applicability. The idea is to build a database of 3-dimensional images of objects, and then use that database to search through 2-dimensional images looking for instances of those objects. Regardless of the orientation of objects in the 2D images, a match should be possible with the identical object in the 3D database. Applications include the automatic generation of image descriptions that could benefit blind persons and those who must work in low-light conditions, as part of facial recognition and target acquisition applications for security and military uses, and in computer vision manufacturing systems.

3.8 Computer Game Design Framework

One undergraduate student developed a simple Java-based computer game as part of a capstone senior projects course. Upon completion of the semester, the student continued to refine, refactor and reorganize the game, to create a well-designed framework for learning about computer game programming.

Beyond game programming, the framework, known as Labyrinth (Figure 4) was purposely made to be appropriate for teaching concepts from nearly any computer science course. Suitable topics include introducing CS0 students to simple Java programming in an accessible and instantly gratifying way, with opportunities for students to make use of the framework in data structures, algorithms, AI, software engineering and many other courses. Extensive documentation for Labyrinth is in preparation, as is a free, open-source distribution version of the game, programmer's guide and complete source code.

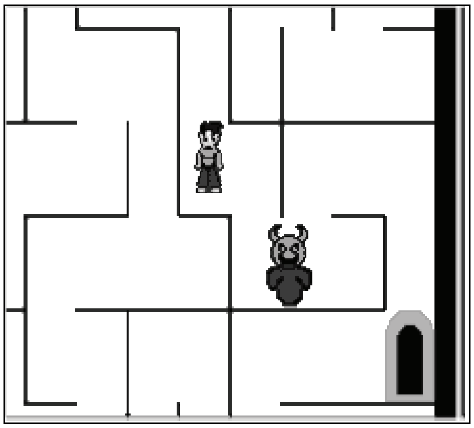

Figure 4. Close up of game play in the Labyrinth computer game design framework.

3.9 Science satire in literacy education

Dihydrogen monoxide is a dangerous and deadly chemical, responsible for vast amounts of death, destruction and mayhem each year. Inhalation of the liquid form can lead to death, while the solid and gaseous forms can cause severe tissue damage and burns. A student is collaborating with the Director to measure the effectiveness and impact of an 8-year-old information literacy web project called DHMO.org. The corresponding web site (dhmo.org) reports in dramatic and breathless fashion of the many dangers and abuses of the deadly chemical dihydrogen monoxide. The project has grown over its lifespan from a humorous form of science satire to an internationally known and used resource for teaching about critical thinking, evaluation of sources and information literacy in general.

4. CONCLUSIONS

By creating a virtual laboratory, such as the ACT Lab, undergraduate students can be drawn into research by providing a personal stake in all aspects of a project. While faculty-directed research is likely to always be the hallmark of graduate-level research, this student-directed, faculty-guided model of research may prove to be an attractive tool for encouraging otherwise reluctant undergraduates to participate enthusiastically in research.

The formation of the ACT Lab has increased student interest in undergraduate research, contributing to our department's efforts to boost student participation through partial research scholarships, research seminars and inclusion of undergraduates in funded research projects. Positive feedback from recent graduates who participated in a classroom implementation of this applied approach to research [10] have been encouraging.. A plan for long-term assessment of the impact of the ACT Lab on those involved is under development.

In addition to overseeing the ongoing evolution of the ACT Lab within its home department and university, plans are being made to broaden its scope to other departments and universities, and to actively pursue collaboration with industry.

5. ACKNOWLEDGMENTS

Thanks to my colleagues in the Computing Sciences Department at Villanova for never once saying that they thought this idea was crazy, and to the students involved for knowing that it was.

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