

CPATH-CB: Computational Thinking Showcase:

Computing Concepts Across the Curriculum

Abstract: *In order to revitalize undergraduate education in computer science and address the need for an increase in undergraduate majors, we propose a novel three-fold approach. First, we create a community of college professors, high school teachers, and an industrial partner to plan and implement an exciting first exposure to computer science. Second, we introduce Interactive Learning Modules as a vehicle for bringing innovation to the classroom. Third, we foster the use of collaboration-based experiences throughout the computer science curriculum.*

Vision, Goals, Objectives, and Outcomes

Problem Statement

1. There is a need for more computer science graduates.

There is a shortage of CS graduates. Of the top ten fastest growing professions, five are computer related [1]. Interest in CS fell by 80% between 1998 and 2004, and has dropped 93% since the 1982 peak of CS majors nationwide [2]. The dwindling interest in computing programs is even more severe for women. Consider graduation rates for women. Unlike many fields where the representation of women has increased over time, computer science has experienced declines in the proportion of female graduates. In order to match future demands for information technology, we need to increase the participation of both men and women. Increasing diversity enhances the breadth of understanding in leadership positions, gives a different perspective in the marketplace, increases creativity, and improves problem solving, particularly in team situations [1].

2. There is a lack of exposure to computer science.

At the 9-12 level, many students get little computer science education. Thus, when students arrive on campus, computer science is often misunderstood, and therefore, not considered as a potential major [2]. This is especially true in Utah (the location for this project) as the few computer programs that are available at feeder high schools typically teach computer science as vocational training rather than in the academic track. Entering students often do not plan to major in computer science as it just is not in their view. This is particularly true for women. Before entering college, they have considerably less experience with computers than their male counterparts [3]. In all levels of education, we believe there are not enough courses which serve as a magnet for the computer science major.

3. Introductory classes are unattractive.

Often, introductory computing classes are unappealing as they focus on tedious details [4]. While programming is typically the first exposure to computer science, it fails to excite many students. Such students often find the introduction to computer science unappealing and intimidating. As Stanford University's John Gardner stated, "Twenty years from now we will look back at education as it is practiced in most schools today, and wonder that we could have tolerated anything so primitive [1]." According to Peter Denning, for most students, it looks like programming is the "make or break entrée into the field; there's no way in unless you can program[5]." Our goal is to showcase and teach the skills necessary to thrive in computer science. We will show the breadth of applications of this "computational thinking" by presenting computer science and X, where X is physics, mathematics, statistics, biology, chemistry, economics, finance, business, and geology. Many previous attempts at a "new way" to teach computer science still look remarkably like the old way – programming as a major component and/or calculus prerequisite required. Computing programs need the new approach this plan identifies.

4. Women are not being attracted to computer science despite forces which should attract women.

Women are underrepresented in computer science. Data indicate that the numbers are low and shrinking. However, in Utah, we see even fewer female students in computer science than national studies report. Since more than half of Utah's university graduates are women, this is particularly alarming. In addition, this shortage of women does not plague other departments in the college of

science. In the past two years for CS majors at Utah State University, women comprise 9% of the total of declared majors. In the same period, 48% of all other science majors (physics, chemistry, biology, mathematics, and geology) are women. One cannot successfully address the issue of a shortage of computer science majors without seeking to increase the number of women in the major.

The fields which women typically choose are often low-paying and have a lesser chance of being employed in their major. In 2006, according to the USU Employment Survey [6], starting salaries are \$49K for CS versus \$28K for education and \$35K for business. National salary statistics indicate \$50.8K for computer science, \$43K for accounting, and \$30.7K for education [7]. Yet, lower salary is not the only disadvantage. While 75% in education report that their job is related to their degree, only sixty percent of those who graduated in business report that their current job is related to their degree compared to computer science, where virtually 100% of the respondents affirm job/degree match [6].

Project Goals and Outcomes:

The overriding goal of this project is to revitalize computer science instruction by developing a set of tools and techniques that can be applied to a variety of computer science classes at various levels including 9-12 and college, and to a diverse population of students. This revitalized program of instruction will serve to increase both the number and diversity of computer science majors, thus addressing this country's critical need for more, better trained computer scientists. We will do this in a variety of ways.

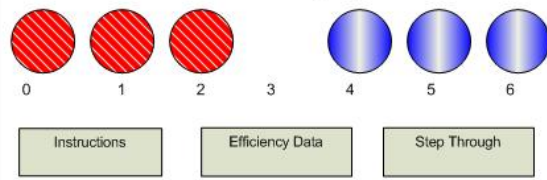
1. Create a community of like-minded individuals to revitalize undergraduate computer science education.

Utah State University, the College of Eastern Utah, and Snow College will work together to test and implement the ideas across a range of classes and institutions of higher education. InTech Collegiate High School, Logan High, and Thomas Edison Charter School will partner at the high school level by beta testing some of these ideas in their classrooms. In the remainder of the document, these entities will be collectively referred to as the Community. We will hold semi-annual meetings for all participant groups at a central location. In addition, we will use video conference calls and Blackboard Vista threaded discussions to collaborate on an on-going basis.

2. Create a library of multi-function Interactive Learning Modules (ILMs) which showcase computational thinking without the often used emphasis on programming and mathematics.

We will produce a Library of ILMs (Interactives, for short) for Computer Science. Each Interactive can be used for multiple lessons, which we term eObjectives. During the community building phase, we will create a website which will facilitate discussions regarding the ILMs, serve as a repository for ILMs, and as a collection point for the discussion of their classroom uses. To illustrate the function of an ILM or Interactive, consider the proposed Interactive illustrated below.

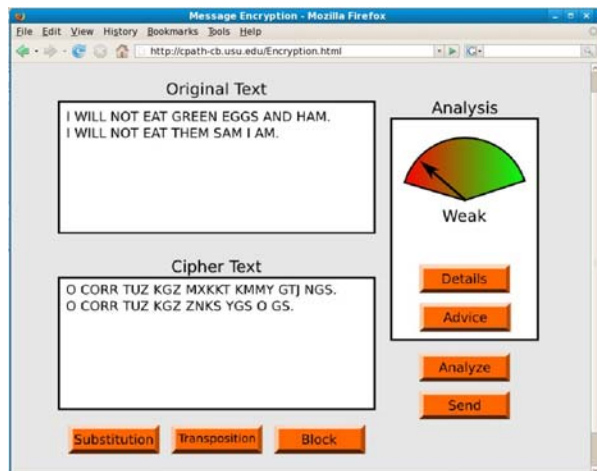
Swap two types of balls.
Moves: next slot or jump over one.



[1] Move the piece in position 2 to position 3.
 [2] Move the piece in position 4 to position 2.
 [3] Move the piece in position 5 to position 4.
 [4] Move the piece in position 3 to position 5.
 [5] Move the piece in position 1 to position 3.
 [6] Move the piece in position 2 to position 1.
 [7] Move the piece in position 4 to position 2.
 [8] Move the piece in position 6 to position 4.
 [9] Move the piece in position 5 to position 6.
 [10] Move the piece in position 3 to position 5.

The balls on the left are to be exchanged with the balls on the right by a sequence of moves. Any ball can move into an adjacent empty slot. Any ball can jump over a single neighbor to an empty slot. Students interact with the module by dragging the balls, identifying (and encoding) a strategy, and observing how the number of steps grows with the problem size. This same basic Interactive would be used in multiple eObjectives. In an introductory course, the exercise demonstrates strategy and planning needed to solve problems. As an exposure to algorithmic thinking, we consider the ability to write an algorithm to solve the problem for a varying number of balls. Abstraction is introduced as we construct rules which are general purpose. Algorithm complexity and analysis are the focus as we seek to evaluate the optimality of our solution.

The graphical interface for another proposed



Interactive is shown to the left. *The students are asked to create a cipher for a text of their choosing. They will experiment with cracking codes by sending their cipher text to others in the classroom.*

Students from various Community campuses will be employed to create Interactive Learning Modules. We partner with Models for Thought, a commercial enterprise dedicated to creative technology in the classroom, for quality assurance and evaluation.

ILMs are motivated by the National Library of Virtual Manipulatives. In 1999, the USU Mathematics Department received the first of two major NSF grants to produce a set of virtual Interactives to allow K-12 students to explore mathematics principles in an

interactive setting [8]. The NLVM is a resource from which teachers may freely draw to enrich their mathematics lessons. This project has met with great success [9, 10] **experiencing 4 million hits per day**. The founder of our industrial partner, Models for Thought, was integral to the creation of the original Math Manipulatives.

Rather than employing a syntax first approach, the modules teach computer science using experiential learning. Many students know very little about computer science, and even after taking an introductory course, view computer science as “just programming”. Our goal is to introduce intriguing problems and basic underlying concepts which computer scientists address, and allow students to experiment with tools built on those concepts in an interactive and fun environment.

Two new computer science classes (Computing Concepts and Cyber Security) have been introduced which seek to attract new majors. Both are general education classes taught at the freshman level. These classes serve as the vehicles through which we introduce our ILMs. These classes are currently being taught without ILMs, giving us a platform for comparison.

The interactive software approach encompassed by ILMs has several advantages:

- closes the gap between what is learned in theory and its use
- improves time-on-task and increases motivation even after failure
- removes the stigma of failure, as missteps are private
- provides a scaffolding [11] for learning, giving cues, hints, and partial solutions
- personalizes learning so that students can control the pace and the topics they pursue
- exhibits infinite patience and provides a self-regulated approach to learning[12]
- encourages women to study computing by showing the practical uses of computer science[13]
- corrects inaccurate impressions of job activities

The ILMs will be used in a variety of different modes – from an integral part of a group assignment to optional exercises used to increase understanding in topics such as error propagation, number systems, data representation, testing, hierarchical decomposition, Boolean logic, compression, searching, etc. Students and/or instructors will select the modules that are of interest to them, but work in a controlled environment in which to hone the skills of self instruction, so important to the computer scientist. It is our belief that the ILMs will provide a superior learning environment[14]. People recall only 10 percent of what they read; 20 percent of what they hear; 30 percent, if audio and visual are combined; 50 percent, if they watch a demonstration; but close to 90 percent, if they perform a task themselves, even if only as a simulation [15].

According to [16], interactive learning experiences in a game-like setting enhance many skills employers want in employees:

- adaptation to rapid change
- decision-making and strategic thinking
- rapid information acquisition
- determining what needs to be done

- analytical thinking
- problem identification
- information synthesis
- solution development
- plan development/execution
- self-direction
- ability to work independently and creatively

Gee [14] agrees that gaming is an excellent way to teach computational thinking. ILMs will appeal to students since they move away from the “tell and test” philosophy often used in traditional instruction. The time spent using digital media by youth from 13-17 has now surpassed the time they spend watching television [17]. ILMs also have the advantage that they are sharable; the student can show a friend what she/he is learning and thus help that friend to learn the same concept. With its clear goals, technology-based exploration is more engaging to the student than standard classroom instruction. The student understands why they are learning something, and by manipulation and testing, is able to grasp the broad contexts and applications of a concept. The modules will follow approaches for good game environments [16] by “keeping the player at the edge of his or her capabilities, moving to higher challenges as mastery is acquired”. We agree that differences in factors — such as experience, ability, and motivation — may have an important [16] effect on how materials need to be presented. The ILMs will give students control over how the material is presented. While interaction is the cornerstone of the approach, a variety of learning preferences will be supported.

A diverse advisory board of students (freshman through PhD) will be used to give feedback on problem selection and explanation of how the demonstrated skills are important to computer scientists. The advisory board graduate students will come from a variety of disciplines such as Education and Instructional Technology and will be motivated by the ability to use the ILMs as a basis for their theses and/or reports. Undergraduate students on the board will come largely from computer science as their participation can be motivated by departmental incentives already in place.

3. At the high school level, provide support to the instructor by making available, online, engaging activities which not only teach computer science skills, but present skills that are applicable to wide range of problems and environments.

An additional goal of this project will be to make our introductory CS breadth physical science class Computing Concepts (which will employ ILMs) a totally online course. This will allow high school students, even in remote settings, to get a quality introduction to computer science while getting college credit. Furthermore, because of the broad applicability of the ILMs, they will be of use for other high school curricula. We will produce a power point presentation which explains how the Interactives can be used in computing curricula and specifically the concepts they teach. High school girls and other underrepresented minorities will be shown using the software in video clips on the Computing Across the Curriculum web site. The ILMs will be publicly available for use by anyone wishing to teach computer science principles in an engaging and informative manner. We will use a Wiki-type environment to host discussions and archive lesson plans on the use of ILMs. We will also visit high schools throughout the state to demonstrate problem solving skills needed in computing, make important contacts with high school math and computer instructors, and showcase the use of course materials that we have prepared.

4. Identify key research questions to improve our understanding of attraction to computer science and persistence in the major.

Research is needed to develop a clear understanding of which features of course work are important for learning and why, and how to best design educational modules which result in desired learning outcomes. Our community of researchers will be of enormous help. As students use the modules, we will gather a myriad of demographic-based statistics to determine what works and what does not work. We will monitor such things as choice of activity, persistence, time on task, use of instructions, perusal of help materials, and success - in order to determine what resources are instrumental for success.

Most course assessments measure the responses of those that complete the course. Thus, those that drop the class literally have no voice in the assessment. In order to *recover* from the problems in the status quo, we need to *discover* the vulnerable times for a student. In this respect, the ILMs will offer a relatively unique tool for assessment by generating data over the entire spectrum of users, not just those that complete the class. The result will be a comprehensive and useful assessment.

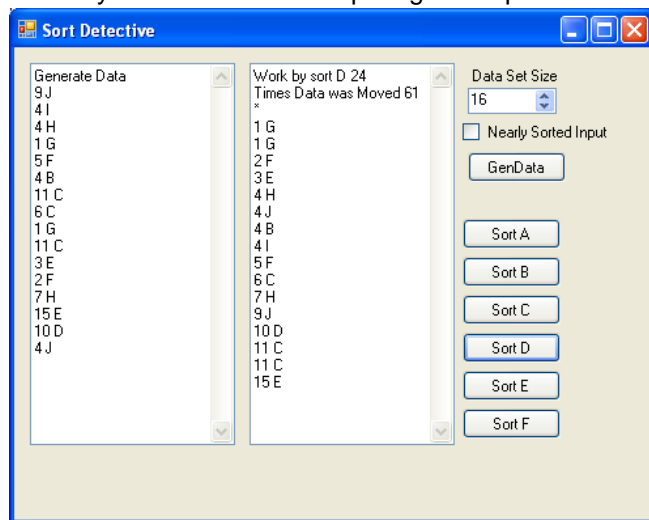
5. Increase the number of freshmen who have a positive exposure to computer science and the number of women who declare CS as their major.

We seek to give wider exposure to computer science in order to reach potential majors who would otherwise not consider computer science. We are specifically targeting individuals in their first year of academic study at a college or university. We have designed two new general education three credit courses to highlight computer science employing minimal programming. This proposal will give wider exposure to computer science in order to reach potential majors, having little computing experience, who would otherwise not consider computer science. We are particularly optimistic about the ability to attract American Indians via using such a program in our regional campus in the Uintah Basin near the Uintah and Ouray reservation. The reservation is the second largest Indian reservation in the United States, covering over 4.5 million acres. The Higher Education program administers tribal grant programs, scholarships, and other on-site programs. Many tribal students are not able to complete a post-secondary degree because they are unprepared for college level academic work. This program will enable students to increase their college-readiness.

The number of freshmen majors selecting computer science has long been held to be a good predictor of graduates four or five years later [18]. The number of female CS majors is at a historic low. Creating classes in the breadth physical sciences not only ensures a high enrollment, it allows us to focus on the breadth of uses for computers and interest in current topics such as computer security. We will capitalize on these varied interests while motivating computing as a major. Current introductory non-major CS courses at USU generally enroll approximately 125 students per year. We anticipate the new courses will attract *an additional 300 students per year*, based on typical enrollment for general education science courses. In addition to demonstrating and teaching key computing concepts we will demonstrate the use of computers in society across a broad range of disciplines. As Sue Rosser argues, “insuring science and technology are considered in their social context may be the most important change that can be made in science teaching for all people, both male and female”[13].

6. Foster the incorporation of Interactive experiences throughout the curriculum

Not only will Interactive computing concepts be central to the introductory class, but ILMs will be provided for use in a variety of classes such as data structures, programming languages, and software engineering.



use in a variety of classes such as data structures, programming languages, and software engineering.

The sort detective shown to the left is an example Interactive that is used in our data structures course. Working in small groups, students are asked to identify which sort each button calls based on how much work is done, how many times the data is moved, and whether or not data is kept in the original order when the keys are identical. This Interactive is enormously effective in teaching sorting concepts like stability and obliviousness. We asked typical final exam questions about complexity, such as “You have two algorithms which are of the same complexity, yet one is much faster than the other on the test data. Give two reasons to explain how this could happen.” In previous semesters, this has been a challenging question. After introduction of the ILMs, many students confidently stated,

“Well, it could depend of the particular input data. In sorting, for example, if data is mostly sorted, some sorts take advantage of that initial order while others do not.”

We will create a wide variety of Interactives. Material will be taught more effectively by emphasizing problem solving. In addition, we will raise the meta-cognition level as students consciously think about how they solve problems.

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