Engaging Non-Traditional Students in Computer Science through Socially-Inspired Learning and Sustained Mentoring

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ABSTRACT

This paper describes a new program for attracting non-traditional students into computer science and retaining them through sustained peer and faculty mentoring. The program is centered on socially-inspired learning, -- learning *in* and *for* a community. It consists of a STEM Incubator course, hands-on projects with real-world applications, a sandbox lab, and a mentoring system that begins in the STEM Incubator course and continues with students who choose to remain involved in projects and courses. Our program is in its second year. Data collected on enrollment and retention and results of student questionnaires show promise for the success and sustainability of the program.

Categories and Subject Descriptors

K.3.2 Computer and Information Science Education

General Terms

experimentation

Keywords

computer science education; socially-inspired learning; mentoring; non-traditional students; active learning

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1. BACKGROUND

1.1 Motivation: To Attract and Retain Non-Traditional Students

Our overall motivation for the STEM Incubator Program is to attract and retain non-traditional students into computer science and other STEM disciplines. We define "non-traditional students" as women, ethnic minorities, and students who describe themselves as not being inclined toward STEM subjects. These groups historically have been under-represented in STEM disciplines. Nationally, while about 50% of college students are female, only about 14% major in computer science. About 30% of college students are African-American and about 15% are Hispanic [22], but they make up approximately 3.8% and 6% of the computer science majors, respectively [28]. At our university, 52.3% of the students are female, 7.6% are African-American, and 5.6% are Hispanic [14], but these under-represented groups account for only 19%, 1% and 2% of our computer science majors, respectively.

Like many universities, we are trying to be pro-active to address this imbalance, recognizing that diversity enriches both our learning environment and the nation's pool of scientists and problem-solvers. Our means of attracting and retaining non-traditional students is through *socially-inspired learning* – learning *in* and *for* a community, motivated by collaboration, caring, creativity, and competition. The practical realization of these ideas is our STEM Incubator Program, which consists of four components:

- A one-hour STEM course offered on a variety of topics, all requiring computational problem-solving.
- Team work on hands-on projects centered on specific real-world applications introducing students to STEM knowledge and skills.
- A sandbox-like STEM Incubator Lab offering a collaborative environment with experimental equipment free for use.
- A sustained mentoring program with both faculty and peer mentors.

1.2 Our Program Compared to Related Work

1.2.1 *Incubator Programs*

The concept of incubator programs, even in computer science, is not new. We aim to distinguish our STEM Incubator by combining inspiration and pedagogy in a well-focused, vibrant, and sustainable program. As part of this effort, we are conducting a long-term study of student learning, changes in student perception of the computer science discipline, and effects of sustained mentoring.

Incubator programs have been around for a long time. Business incubators, which began in the 1950s and burgeoned through the 1980s and beyond, are targeted toward helping early-stage companies get started. There is even a national organization for business incubators [13]. Technology business incubators are also common, often emerging as university/business collaborations [12,19].

Our STEM Incubator Program combines a for-credit introductory-level course with involvement in undergraduate research by means of experimental projects. We have established a relationship with our university's Innovation, Creativity, and Entrepreneurship program, enabling subsequent opportunities for entrepreneurship development [1]. Another participating program providing socially-inspired learning opportunities for our STEM teams is the Center for Energy, Environment and Sustainability.

1.2.2 *Mentoring Programs*

A proliferation of mentoring programs can be found in STEM education, many of them industry-affiliated or grant-funded [7,18,21,23,24,26].

Our mentoring program is distinguished by providing the means for both *peer (horizontal) and faculty (vertical) mentor* relationships that are *sustained* over the students' computer science education. We also have a trained mentor coordinator to help develop peer mentoring skills among the students.

1.2.3 *Socially-Relevant Vs. Socially-Inspired Computing*

Socially-relevant applications of computer science have been extensively explored as learning motivators in recent years [3,4,16,17]. Our concept of *socially-inspired* learning extends the idea of relevance to *context* and *environment*. Our intent is to make learning interesting and relevant by giving students a sense that they are working *in* a *community* of learners and *for* the benefit of the broader community in which they live. Elements of community are *collaboration* (working in groups), *caring* (working for the benefit of others or the environment), *creativity* (curiosity in the exploration of the interplay among computation, STEM disciplines, and the arts), and *competition* (a natural motivator).

Collaboration takes place primarily within small teams of apprentices along with student and faculty mentors. Collaboration is also often interdisciplinary, as exemplified in STEM Incubator courses that have focused on applications related to remote sensing and conservation, bioinformatics and computational physics, digital music, digital image processing, and network security. Caring refers to the relevance of STEM team work in addressing problems of society [5,15], including the immediate campus community in which the students live. Creativity is emphasized in projects of all types, but most obviously in the arts-related ones. Teams are encouraged to explore their general topic freely, formulating both the problem and solutions in the process. Healthy competition is motivated by public oral and poster presentations, demos, etc. We see the socially-inspired work taking shape within our STEM Incubator program as a catalyst for subsequent scientific, artistic, business, and entrepreneurship student ventures.

1.2.4 *Undergraduate Research and Vertically-Integrated Programs*

Closely related to science incubator programs in academia are programs that involve undergraduates in research. Two examples of such programs are the Freshman Research Initiative at the University of Texas [6] and Georgia Tech's Vertically-Integrated Projects (VIP) Program [2,8]. In the program at Texas, freshmen become part of 30-student cohorts working on research projects in a wide variety of science applications. This program also provides peer mentoring. The Georgia Tech VIP Program is vertically-integrated in that it involves students from the sophomore to the PhD levels. Projects are multidisciplinary.

Our STEM Incubator Program is similar to the Texas initiative in that it engages freshman in research and experimental projects within small teams. It is similar to Georgia Tech's vertically-integrated concept in that we encourage students to remain involved in projects that they first encounter in their STEM Incubator course (or migrate to projects on related topics), maintaining their peer and faculty mentors. Also, in addition to upperclassmen, a few MS-level graduate students have helped out in our STEM courses as mentors.

Like the Georgia Tech program, our program encourages students to remain involved in projects after the completion of their course. We think that a result of our socially-inspired learning approach, students will feel *invested* in their work and will *want* to continue to be involved. In the 2013-2014 academic year, several of our STEM Incubator students have leveraged their STEM Incubator work to propose and apply for summer research, funded by our university's undergraduate research fellowship program or faculty grant funding. Summer 2014 projects included algorithms for creative 2D image manipulation, 3D bio-printing, and wearable sensors and algorithms for stress detection.

1.2.5 *Computational Problem-Solving*

A distinguishing feature of our STEM Incubator Program is not only the relevance but also the intentionality we give to computational problem-solving. Although our sections of the STEM Incubator course vary by topic, they share learning outcomes, listed below (and condensed for space).

At the end of the STEM Incubator Course, students will be able to

- ***describe*** and ***apply*** strategies for ***identifying and refining*** a computational or technology-based problem.
- ***describe*** and ***apply*** strategies for ***solving*** a computational or technology-based problem.
- ***describe*** and ***apply*** strategies for ***troubleshooting or debugging*** when roadblocks are encountered in a computational or technology-based problem.

Some of these concepts and skills are expected to be learned spontaneously as students are guided through real-world problem solving. Group meetings, short presentations with required key points to cover, and retrospection on their projects help students to become aware of what they have learned and how they have applied it. Templates of student slide presentations are available at http://csweb.cs.wfu.edu/~burg/STEMIncubator/CSC192Fall2014.

2. IMPLEMENTATION

2.1 The STEM Incubator Course

Our practical means of attracting non-traditional students is a one-hour course called the STEM Incubator. Each section of the course has a focus application area in which students develop a hands-on project. The course is being offered for the third time in fall 2014. Interest areas have included mobile apps for campus life; wearable sensors development for health applications; quadcopter/drone development for conservation; digital sound and music for the arts; the art and science of 2D imaging; bioinformatics for genetics; and network hacking and security.

The course is offered at two-levels: the apprentice level and the mentor level. Mentors must have taken at least one computer science course. Some mentors have experience in the application area, and/or are already working on an on-going project with a STEM professor. There are no pre-requisites for apprentices.

Although all sections share the learning outcomes described above, the manner in which individual instructors handle their courses can vary greatly. Some sections are open-ended in problem definition, while others begin with a fairly well-defined problem. Students from all sections meet together as a group four times during the semester, sharing their problems and results in lightening talks that focus on approach and problem solving skills. Brainstorming among groups is particularly encouraged. The semester finishes with oral presentations illustrated with posters. In addition, this Fall 2014, teams will be required to submit general-audience three minute videos to be shared online.

Enrollment in sections of the course is limited to about ten students, and usually the sections are closer to six. A ratio of one peer mentor to about three apprentices works well. Although enrollment for apprentices is not limited to freshmen, we give freshmen priority. Apprentices are being recruited during the summer before their freshman year by our University's Office of Academic Advising and through word of mouth during the Fall for the Spring semester. Academic advising reports a high rate of students in the waiting list for the STEM Incubator course.

2.2 The STEM Incubator Lab

In conjunction with the STEM Incubator course, we have a STEM Lab that serves as a sandbox for students and an environment to foster a community of learners. Students in the Incubator Program (those in a course or involved in on-going projects) have access to the STEM Lab 24/7. The Lab is equipped with computers and "toys" for experimenting – Makey-Makeys, Raspberry Pis, Kinect cameras, a 3D printer, a digital audio workstation for music production, GPU computers, hackable computer networks, quadcopters, simple electronic tools, and so forth. Students work and interact in the lab, seeing each other's projects and exchanging knowledge and ideas.

2.3 Motivation for Faculty Participation

Faculty have been willing to teach STEM courses in spite of the fact that the course becomes a one-hour overload from the usual teaching load. The courses are attractive to some faculty because they offer an opportunity to experiment and explore special interests in a way that may not be practical with their normal research students. Faculty from departments other than computer science are also directly or indirectly involved as mentors.

Having peer mentors in each team lessens the burden on the faculty. The mentor/apprentice design of the program encourages the creation of sustained experimentation-and-research teams that can benefit a faculty member's own research program. Apprentices are introduced to on-going projects by mentors and they may become mentors themselves, leading to natural evolution and development of projects. In principle, the mentors can become more effective researchers for the faculty.

2.4 Example Projects and Outcomes

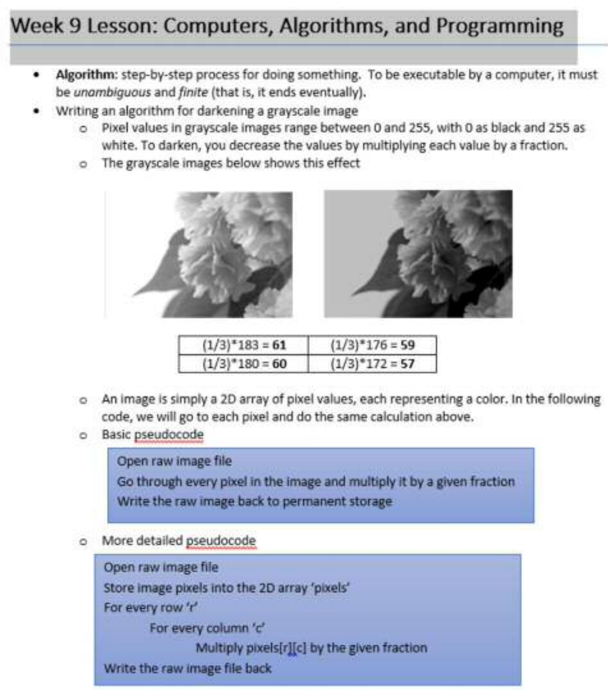
2.4.1 Projects and Other Material Shared

The STEM Incubator Program reflects the strong interest among our faculty in computer science education. Supported in part by curriculum-development grants that correlate with the STEM Incubator Program, curriculum material has been developed (and is continuing to be developed) to be used in STEM Incubator courses.

Our STEM Incubator program is structured in a way that can be replicated at other universities, and our material is freely shared for others who wish to implement a similar program of their own.

Example projects are illustrated at our website, some by means of short videos, to offer ideas for faculty at other institutions [26]. Among these projects are those outlined below.

2.4.2 Curriculum Material for Digital Media



Week 9 Lesson: Computers, Algorithms, and Programming

- **Algorithm:** step-by-step process for doing something. To be executable by a computer, it must be *unambiguous* and *finite* (that is, it ends eventually).
- Writing an algorithm for darkening a grayscale image
  - Pixel values in grayscale images range between 0 and 255, with 0 as black and 255 as white. To darken, you decrease the values by multiplying each value by a fraction.
  - The grayscale images below shows this effect

(1/3)*183 = **61**	(1/3)*176 = **59**
(1/3)*180 = **60**	(1/3)*172 = **57**

  - An image is simply a 2D array of pixel values, each representing a color. In the following code, we will go to each pixel and do the same calculation above.
  - Basic pseudocode

```
Open raw image file
Go through every pixel in the image and multiply it by a given fraction
Write the raw image back to permanent storage
```

  - More detailed pseudocode

```
Open raw image file
Store image pixels into the 2D array 'pixels'
For every row 'r'
        For every column 'c'
                Multiply pixels[r][c] by the given fraction
Write the raw image file back
```

Figure 1 Excerpt from 2D imaging exercise

In summer 2014, curriculum material for the "Science and Art of 2D Imaging" STEM course was created in a collaboration between the faculty instructor and one of the student mentors. This material consists of ten lessons and related assignments that move students from high to low levels of abstraction in creative manipulation of digital images. Using a digital image processing tool at a high level of abstraction, students learn concepts of pixels, resolution, image size, file types and compression, histograms, transform functions for contrast or brightness, convolutions, and blending modes. With the help of the mentors, the apprentices are introduced to the mathematics and algorithms underlying these concepts, and they begin to see how a computer program could be written to accomplish the functions provided by GIMP. By this means, the apprentices are also exposed to basic programming logic and constructs. Simple exercises guide them through the material, and the learning is motivated by a creative final project that they work on incrementally throughout the semester. A lesson and related exercise are illustrated in Figure 1 to give the flavor of the curriculum material [9].

In the area of digital sound and music, a similar learning module has been created to move students from high to low levels of abstraction in audio processing. In this module, students learn about digitization, sampling, quantization, the representation of sound through sinusoidal functions, frequency related to pitch, amplitude related to loudness, time domain vs. frequency domain representations, musical frequencies and harmonics, modulation, LFOs, and amplitude envelopes. With a base set of MATLAB or Octave functions, the students are challenged to "hand-craft" their own musical piece by summing frequencies; experimenting with square, sawtooth, triangle, and sine waves; applying amplitude envelopes and LFOs for tremolo or vibrato, and so forth. (See http://csweb.cs.wfu.edu/~burg/MATLAB&OctavePrograms/).

2.4.2.1 Drones, Health, and Art: An Exploration of Sensor Applications

Data-collecting sensors are becoming ubiquitous across all aspects of society. Optical sensors collect image data remotely, GPS sensors track geographic location, accelerometers track motion, and others can track heart rate and physiological data. One of our STEM Incubator courses explores the use of these types of sensors for conservation, health, and alternative human-computer interaction purposes. Current and past projects include quadcopter development, heart rate monitors for stress awareness, translation of American sign language to voice [10], Arduino based bat sonar systems, and alternative mouse design for disabilities.

Figure 2 Working on novel input devices

2.4.2.2 Remote Sensing for Music Education and Exercise Therapy through Music

One STEM course gave students an opportunity to experiment with remote sensing (Kinect cameras) in applications related to music. The first experiment (done as a prototype for the following semester's STEM course) used remote sensing coupled with MAX/MSP programming to create systems for ear-training in perfect or relative pitch [11,20]. The following semester, students did a variation of this application, creating a system to encourage exercise and motion by sensing user movement and "measuring out" musical strains accordingly [27].

2.4.2.3 Bioinformatics

The Bioinformatics STEM course provided students the opportunity to explore the role that computers and algorithms play in modern biology and to experience interdisciplinary interactions between computer scientists and biologists. The first focus of the course was for students to investigate mechanisms for determining how to define and efficiently compute DNA and protein sequence similarity, within the real-world context of needing to be able to rapidly identify a new virus. The second focus was to process, with statistical filtering, clustering, and machine learning algorithms, microarray datasets in order to determine subsets of genes with interesting behaviors. The course ended with a tour of the lab of a collaborator from the Department of Biology that allowed the STEM students to see the source of the microarray data they analyzed and to see and hear why such analyses were important to be undertaken in the context of modern agriculture.

2.4.2.4 The Internet of all Things

As the Internet continues to evolve to interconnect a larger and more diverse set of devices, maintaining cyber security has become more important. This STEM course sought to introduce students to offense and defense approaches by tracing the general steps of a cyberattack (reconnaissance, access, privilege, foothold, and cover). At each step, students were introduced to basic security concepts and current tools, and given a challenge for that week. For example, for the access step, a web server was created and students used hydra (a web-form password cracker) to gain access to a protected page. For the defensive counter measure, students learned about secure passwords and well-established web access policies. As a final project, students were challenged to practice all steps of a standard attack against set of servers, which is considered a stepping-stone attack (with movement through a series of servers required). The course relied heavily on Virtual Machines (VMs), Virtual Local Area Networks (VLANs), and firewalls to ensure the students stayed within designated areas of the campus network. Virtualization also greatly reduced the administration of the course since any damaged systems could quickly be reestablished.

3. RESULTS

3.1 Demographics

Our STEM Incubator courses thus far have had good success attracting underrepresented minorities and women. Demographics for all apprentices are shown in Table 1, while Table 2 shows the demographics for freshmen only.

Table 1 Demographics of STEM Incubator Courses

Semester	Total # students	African-American	Hispanic	Male	Female
Fall 2013	30	3 10%	3 10%	18 60%	12 40%
Spr 2014	46	1 2%	4 9%	27 59%	19 41%
Fall 2014	47	2 4%	3 6%	30 64%	17 36%

Table 2 Demographics of STEM Incubator courses, freshmen only

Semester	Total # freshmen	African-American	Hispanic	Male	Female
Fall 2013	24	2 1%	2 1%	14 58%	10 42%
Spr 2014	20	1 5%	3 15%	11 55%	9 45%
Fall 2014	23	2 9%	1 4%	14 61%	9 39%

Table 3 Demographics of computer science majors at WFU

	Total # CS Majors	African-American	Hispanic	Male	Female
CS Majors	84	2 2%	2 2%	68 81%	16 19%
CS Minors	25	0 0%	0 0%	13 52%	12 48%

In light of the fact that less than 20% of our majors are currently female, having more than 40% women in our STEM courses is a good initial showing. We achieved this result even without the more targeted recruiting that we are now putting into place. We observed almost no difference between the African-American and Hispanic demographics of computer science majors and the STEM Incubator courses, but this is likely the result of our campus-wide demographics.

3.2 Survey Results

Apprentice students were requested to complete a pre-course and a post-course survey relating to the students' interest in and self-perception of skills related to STEM, computer science, and problem solving. Questions were either free-response (for example: *Likely Major?*) or on a 5-point Likert scale. A total of 29 and 22 students enrolled in the STEM courses completed the pre- and post-course surveys respectively during the spring 2014 semester, with 16 of those students completing both surveys. A little more than half of the students submitting surveys were freshmen.

At our university, students cannot select their major until the end of their sophomore year, so analysis was done for three groups: all apprentices, freshman and sophomore apprentices, and freshman-only apprentices.

Even with the small sample size, there are encouraging initial results indicated by the survey. Responses were averaged across the pre- survey respondents and the post-survey respondents. The largest positive change observed was for the question *How would you rate your logical problem solving skills at this time* (1- *Quite Weak to 5 – Very Strong)*? for which increases on the Likert scale of 0.28, 0.41, and 0.48 were observed when breaking the surveys out by all apprentices, freshman and sophomore apprentices, and freshman-only apprentices respectively. When only students who responded to both surveys were analyzed, even greater increases were seen in response to this question. Pre- to post-course increases of 0.32 and 0.34 were observed for freshman and sophomore and freshman-only students respectively in responses to the question of *What is the likelihood you will minor in a STEM subject at WFU?* Other smaller increases were observed that warrant following up on in future semesters - primarily in the responses from first-year students, the primary target population of the STEM program.

3.3 Retention

The STEM Incubator Program has had good initial success in retaining freshmen in STEM courses after they take the first STEM Incubator course. Of 33 freshmen who took the STEM course in Fall 2013, 17 of whom were from under-represented groups, a significant number took subsequent science, computer science, or mathematics courses, as shown in the table below.

One of the most encouraging results of the STEM Program is manifested in the continued involvement of students in research and experimental projects with faculty beyond the initial STEM Incubator course. The program is showing success in engaging students in the discipline with interest and enthusiasm. Five students have repeated as mentors in Incubator courses. One former STEM student is now working on 3D bio-printing with the Wake Forest Institute for Regenerative Medicine.

Table 4 Retention in STEM, after STEM Incubator course

freshmen who took STEM Incubator course, Fall 2013	# who took a subsequent natural science course	# who took a subsequent computer science course	# who took a subsequent mathematics course
33	12	4	15

4. DISCUSSION

In this paper, we presented our approach for attracting and retaining non-traditional students through a socially-inspired learning process. Creating small teams of apprentices, student mentors, and faculty mentors under an STEM Incubator umbrella is a key component of this process. A one-hour credit course implemented through a number of specialized sections is used to elicit student work. Through our STEM Incubator Lab, students are also provided a sandbox environment for collaboration, exploration, and creativity.

Early results from our STEM Incubator program are very encouraging. Our University's Office of Academic Advising reports a high number of incoming students interested in the program. Information about the program is disseminated through the computer science department website. Because the program is still in its early stages, STEM retention rates past major/minor area declaration and after graduation are not yet determined. However, we believe retention will occur as a result of our sustained apprentice/mentorship approach and student investment in being a part of a community working on real-world projects.

5. CHALLENGES AND FUTURE WORK

A fundamental challenge in this program is finding and attracting the right students – non-traditional STEM students who have *unrealized aptitude* for computational science. We are getting help from educational specialists in refining our pre- and post-course surveys, with the intention of including a small questions that measure problem-solving ability before and after the STEM Incubator course. We are also beginning collaborations with K-12 educators and educators who have been active in women-in-science initiatives. These collaborations may help us establish coherent paths for non-traditional students from K-12 to STEM education in college.

Our plans for continued development of the STEM Incubator program include:

- more targeted recruiting, including outreach to high schools
- refinement of the mentoring program in collaboration with our mentor coordinator
- increased data gathering to assess the program's success in attracting and retaining non-traditional students
- continued development of curriculum material, including a refinement of our learning objectives geared toward computational problem-solving
- dissemination of the program's methods and results

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