Integrating Sustainability Into Undergraduate Computing Education

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ABSTRACT

In the past few years sustainability and green computing have received tremendous interest across the world. Computing plays a critical role in our society, thus it has a special responsibility for sustainability and green movement. In this paper, we advocate sustainability integration into undergraduate computing education. We present three sustainability integration strategies, our efforts to develop a green computing course and learning modules, and course evaluation. We believe that sustainability integration will help prepare our graduates with computing competencies, multi-disciplinary knowledge, and computational thinking to create a sustainable future.

Categories and Subject Descriptors

K.3.2 [Computers and Education]: Computer and Information Science Education

General Terms

Human Factors

1. INTRODUCTION

“To me, going green is the great challenge - and opportunity - of the 21st century”, said by columnist and best-selling author, Thomas L. Friedman [7]. President Obama’s economic stimulus plan also has a strong green hue. The plan would put half a million Americans to work on energy projects and push America toward a green and sustainable future [19].

People around the world are increasingly aware of and concerned about sustainability and green movement. Computing plays a critical role in our society, thus it has a special responsibility for social development and welfare of human beings - not only for this generation but also for future generations. Despite the continuous efforts in the computing community, today’s undergraduate computing education often fails to address our social and environmental responsibility [12].

In this paper, we present our efforts to revitalize undergraduate computing education by understanding, advocating, integrating, and assessing the study of sustainability in computing education; by doing so, we will better prepare our graduates with computing competencies, multi-disciplinary knowledge, and computational thinking to create a sustainable future.

2. WHAT IS SUSTAINABILITY?

In the past few decades sustainability has received tremendous interest across the world. Sustainability is often defined as “meeting the needs of the current generation without compromising the ability of future generations to meet their own needs” [18]. The term is often used in reference to the potential longevity of environmental and human ecological systems, such as climate, agriculture, forestry, and human communities in general.

The widespread adoption of Information Technology (IT) has thrown the spotlight on the environmental and social impact of computing systems and IT infrastructure. For example, the power consumption of data centers in the U.S. doubled between 2000 and 2005, and will likely triple again soon [25]. In 2006, the U.S. Congress passed bills to raise the IT industry’s role in energy and environmental policy to the national level [2].

Green computing is the study and practice of using computing resources in an energy efficient and eco-friendly manner [11, 17]. It is a holistic approach that stretches from power, to waste, to application, to education. Green computing represents a dramatic change in the priority of IT industry from the traditional economic cost/benefit model to the new sustainable model by mutually advancing economic, environmental, and social goals.

3. WHY STUDY SUSTAINABILITY?

Sustainability is and will continue to be an important issue for the next few decades. Many professional groups including the Royal Academy of Engineering and the National Academy of Engineering have already addressed sustainability through their professional guidelines and codes [21, 22]. The Accreditation Board for Engineering and Technology (ABET) also called a shift towards sustainability education in engineering disciplines [6]. As educators in the computing discipline, now it is our responsibility to integrate sustainability into undergraduate computing education.
Unfortunately, despite the clear calls, today’s computing education acts slow to such a shift towards sustainability education [10]. In Association for Computing Machinery (ACM) computing curricula [4], there is no mention of sustainability or similar terms until the latest update in 2008. Researchers have identified barriers and challenges in sustainability development in computing education [12]. Some of the barriers include: a fundamental lack of interest, a lack of staff training, a lack of tradition, and a lack of priority.

We argue that sustainability and green computing study in computing is not only critical and imminent for the long term benefit of human beings, but also has the potential to attract more students to computing, increase workforce diversity, and improve the retention rate of computing students.

One of the major challenges faced by the engineering education community is the declining proportion of students choosing engineering as a profession. From 1994 to 2004, enrollment in U.S. higher education institutions increased by 20%, however the number of engineering degrees conferred remained relatively flat [5], with little diversity overall [20].

Computing education faces an even more serious enrollment problem. The percentage of incoming undergraduates who indicated they would major in computer science declined by 70% between 2000 and 2005 among all U.S. higher education institutions [26]. Research [13] indicates that it is partly attributed to students’ perceptions that computing is boring, geeky and asocial.

According to a survey of 3,000 teens, the 14-18 year olds are committed to equality, and prefer companies that act responsibly for a clean environment [23]. According to the Women’s Experiences in College Engineering Project, women leave engineering programs not because of poor academic performance, but because of a lack of connection to their goals of helping society [8]. These studies suggest that young people don’t choose engineering in part because this profession is perceived to have little connection to improve the world around them.

Recent research indicates that sustainability is attracting the attention of students around the world. Some studies suggest that sustainability curricula may increase the recruitment and retention of women and minority in engineering [27]. Successful examples of sustainability integration include chemistry [27], civil engineering [16], environmental engineering [14] and mechanical engineering [9].

The authors in [12] examine the status of education for sustainability in computing. Despite the importance of this topic, it seems that there is little room left for sustainability study in the over-crowded computing curricula [15]. The existing work on this topic is limited and isolated. For example, several computing courses with sustainability integrations are described in [3, 10]. A software engineering course using a sustainable approach is introduced in [28]. A sustainability infused Computer-Human Interaction(CHI) activity is described in [1].

Although there is no direct evidence to support sustainability integration in computing, the literature review indicates that there is sufficient evidence to show the positive impacts of sustainability integration in non-computing engineering disciplines.

It is our contention that by adding sustainability to computing education will escalate interest in computing among those socially-minded young adults, both male and female. Sustainability studies will help students realize their social and environmental responsibility, motivate them to serve the community, and make the world a better place to live. By being rewarded with a feeling of accomplishment and making differences, more students, including women and minorities, will be attracted to computing, and the retention rate of college students may also be improved.

4. CURRICULUM DEVELOPMENT

4.1 Barriers and challenges

We list a group of barriers for sustainability integration into computing education (identified by [24]) along with our comments.

- A fundamental lack of interest. IT industry has a poor track record in term of environmental protection and sustainability development, so does computing education. However, the sharp rising cost of energy in the past few years has forced people to re-think their IT investment strategy and adopt energy-efficient computing. Principles such as economic viability, social responsibility, and environmental impact must be taken into account as a whole when designing, implementing and managing computing systems.

- Staff training. Lack of training and expertise is indeed a major obstacle. However, sustainability is an on-going research/education topic in many other engineering disciplines. Through true collaboration, computing professionals can borrow expertise, lesson learned, and good practice from other fields. Professional workshops, seminars and online tools will also bring people from different disciplines together and introduce sustainability to computing professionals.

- A lack of tradition. Indeed this should not be a barrier since computing itself is a young and fast-growing discipline. The question that the computing education community should ask is: how can we take the lead in the shift from traditional cost/benefit model to the new sustainable model instead of being left behind?

- A lack of priority. There are many important issues in computing education. It seems not too much space left for a “buzz” word like sustainability. However, we hope that this paper may help people realize that sustainability has the potential to revitalize computing education. This will move sustainability to the top priority list in computing education.

4.2 Solutions and strategies

Admittedly, some arguments against sustainability study in computing are legitimate and based on reality, for example, lack of funding and support, over crowded computing curricula. In this paper, we propose three approaches for sustainability integration in computing (Figure 1).

The first option is probably the most straight-forward approach, by developing a new course named “green computing”. The new course will cover selected sustainability and green computing topics.

The second option is a low-cost, modular, progressive approach. We will design and develop independent green computing learning modules and projects. These modules and projects can be easily plugged into the existing computer courses with little or no cost. This approach is ideal for sustainability topics which don’t require transformative changes in computing courses.
The third option is an integrative and transformative approach. We hope to be able to completely re-design some computing courses with sustainability as one of the top priorities. For example, there exists a significant body of research/education work on computer architecture, operating system, database system, and resource management which largely focus on pure performance or cost. By promoting energy to a first-class resource, people will gain new insights and findings on how to achieve energy saving in the current IT systems.

4.3 Development of a green computing course

An undergraduate course SAT4541 - Green Computing & Network Services was developed by the author, Dr. Yu Cai at Michigan Technological University.

The SAT4541 course covered the following green computing topics:
1) General concepts and principles of sustainability and green computing.
2) Background and motivation for green computing.
3) Server virtualization technology, including what is virtualization, how virtualization works, typical products like VMware and Xen, how to use virtualization to save energy.
4) Green data center, including why saving energy is important to data centers, common energy saving practices in data centers.
5) Power-aware computing, including energy-efficient hardware innovation, energy-efficient software innovation, memory and disk management, benchmarking and assessment.
6) Energy information system and smart power management.
7) Electronic waste disposal and recycle.
8) Regulatory compliance.

The new SAT4541 course was designed to piggyback on an existing 3-credit network service course. The 1st half of the semester is on advanced network topics (such as directory services), and the 2nd half of the semester is on green computing. This design allows us to infuse green computing in the overly-crowded computing curriculum.

The new SAT4541 course was taught in Fall 2008 (35 students), Summer 2009 (7 students), and will be taught again in Fall 2009 (estimated 37 students). Most students are seniors majored in Computer Network and System Administration (CNSA) at Michigan Technological University. A small portion of the students are from CS, ECE and bioinformatics.

4.4 Development of green computing course modules

We developed the following green computing modules that can be used independently in other computing courses.

1) Green computing introductory module: including general concepts and principles of sustainability and green computing, electronic waste disposal and recycle, and regulatory compliance. This module can be used in a CS introductory course or a CS ethical course.
2) Server virtualization module: including what is virtualization, how virtualization works, typical products, and how to use virtualization to save energy. This module can be used in an operating system course or other related courses.

The server virtualization module was used in SAT4600 - Advanced Internet Technology in Spring 2009 (45 students). More course modules will be developed and tested in the future.

4.5 Development of green computing senior design projects

The following green computing senior design projects have been developed:
1) Solar Powered Computer: this project is to design and build a prototype to use solar energy as power supply for a laptop computer. The system includes a solar panel, a battery, and interface to a laptop. Solar technology is still an expensive technology today, and the purpose of the project is to build a proof of concept prototype.

2) Measurement of energy consumption curves in computing systems. This project is to study the energy consumption curves of real world computer systems. The team also developed a prototype of wireless watt meters which can collect energy consumption data wirelessly from multiple sources.

Table 1: Exit survey questions and the average responses in SAT4541 green computing course

<table>
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<tr>
<th>Section 1. As a result of your work in this class, how well do you think that you now understand each of the following?</th>
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<tbody>
<tr>
<td>1. What is green computing?</td>
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<td>2. What is sustainability?</td>
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<tr>
<td>3. How to set up virtual machines and optimize their performance?</td>
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<td>4. What is energy information system?</td>
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<td>5. What are the best practices to build energy efficient data centers?</td>
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<td>6. How to optimize power management?</td>
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<td>7. How to save energy in computing hardware?</td>
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<td>8. What is power-aware computing?</td>
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<td>9. How to recycle e-waste?</td>
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<td>10. How to ensure regulatory compliance?</td>
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Section 2. How much of the following do you think you will remember and carry with you into other classes or aspects of your life?

| 1. Understanding the concepts of sustainability and green computing | 3.7 |
| 2. Feeling comfortable with virtual machines | 4.4 |
| 3. Feeling comfortable with other major techniques in green computing | 3.9 |
| 4. Understanding how green computing may be applied to other fields | 3.7 |
| 5. Feeling comfortable to use computational thinking | 3.9 |
| 6. I have strong enthusiasm in green computing | 4.4 |
| 7. I am confidence in my ability to do computing | 4.3 |
| 8. I want to work for a company who really cares about green movement | 3.4 |
| 9. I want to help improving the world around me with green techniques | 3.6 |
| 10. I want to learn more green technologies | 3.6 |

5. COURSE ASSESSMENT

Students who took the SAT4541 green computing course completed an exit survey to measure changes on content knowledge, attitude, and behavior on a voluntary base. Preliminary survey data was collected and analyzed. The response ratio is 83% (35 responses out of 42 students who took SAT4541 in Fall 2008 and Summer 2009).

There are more than 60 questions in the SAT4541 exit survey. To save space, only selected questions and average response results are showed in the following table 1.

For each survey question, there are five scales: 1- No help, 2- A little help, 3- Moderate help, 4- Much help, 5- Very much help. Students check one value for each question on each scale. If the question is not applicable, check "0 - N/A". Students may add a comment for any item in the text box at the end of the survey.

The official course rating of SAT4541 is 4.7 (on a 1 to 5 scale), which is among the top 10% of all the course ratings at Michigan Tech. Most students think the course help them learn green computing technologies. The students understood green computing concepts and techniques well (from section 1 in the survey). The students also maintained high confidence and enthusiasm in green computing (from section 2). However, the impact of a single course on students' future decisions seems less significant (from section 2).

6. CONCLUSION

In this paper, we advocate sustainability integration into undergraduate computing education. We present three sustainability integration strategies, efforts to develop a green computing course and modules, and course evaluation. Our work is still in the development stage and there are many challenges and questions not answered. It is our hope that the research results can increase the awareness of green computing movement, produce a valuable sustainability education model that can be used elsewhere, and provide insights for further sustainability and green computing education.

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7. REFERENCES


