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Abstract— **The concept of green computing has become a popular label employed by all major IT corporations when promoting either their hardware as energy efficient or asserting that their software solutions improve work performance and reduce the carbon footprint. Yet, how one addresses sustainability in computing is still a developing area and without clear guidelines or standards. Preparing students on topics of computing sustainability is thus essential for ensuring the future professionals have the skills to tackle such an important challenge. In this paper we propose a sustainability module we developed for an introductory computing course. We start by providing a justification of our work, motivated by the students' attitudes towards green IT as emphasized by an initial study. We continue with a description of the module and the class it was prepared for. Finally, we analyze the impact the module had on the students by discussing the results of an assessment survey. Our work provides a stepping stone for innovative integration of sustainability in computing by motivating students to become responsible global citizen and professionals.** *(Abstract)*

Keywords - sustainability, green computing, information technology, carbon footprint.

I. INTRODUCTION

The concept of *green computing* has become a popular label employed by almost all major IT corporations when promoting either their hardware as energy efficient or asserting that their software solutions improve work performance and reduce the carbon footprint [1]. The increased awareness the concept of sustainability receives from the IT industry is due to a growing concern the potential customers have on the impact climate changes have on the human society [1] . The efficiency of promoting green IT is further enhanced by the fact that sustainability in computing is primarily associated with reduction in energy consumption, thus also potentially reducing the business costs [2]. Moving beyond energy consumption by data centers (estimated at 2% of worldwide consumption [3]) the impact consumer computing devices (such as laptops, desktops, tablets, smartphones, etc.) have on the environment is also significant. The ever reducing life cycle for such devices is prone to create additional challenges down the road [1], [4].

Integrating environmental concerns in Information Technology is thus highly desirable and relies significantly on the ability of the professionals to adopt green practices [5]. Yet the learning opportunities in green computing are still limited. In an extensive survey undertaken in 2011, American researchers started with ambitious hypothesis that higher education institutions are actively engaged in teaching green IT [6]. Through surveys, the researchers collected data on 89 colleges and universities (24% of which were non US) on degrees, courses, or modules that the institutions offer or plan to offer. The results were quite surprising. Nine institutions (11%) indicated the existence of degrees. However, most of these degrees were general sustainability programs lacking any green computing course and the rest were not found in any documentation available from the university (suggesting newly introduced programs, or again incorrect classification). When individual green computing courses were concerned, 17 institutions (19%) responded that such courses exist or are under development. Again here some of the responses could not be verified, leading the authors to suggest that the offerings may be either miss categorized as green IT or show up as special topics courses. Overall, the study's results suggest that while popular interest on computing sustainability exists, and while industry's desire to promote itself as green is high, academic institutions have yet to provide the learning environment needed for the green IT professionals.

Part of this disconnection lays in the relative novelty of the topic and the lack of structured materials such as textbooks. Recognizing such effort, a recent ACM ITiCSE working group aimed to systematically review the currently available green computing materials [7]. The participants' started by first selecting a set of assessment questions grouped under four categories: philosophy (i.e. role of computing, definition of sustainability), practice (i.e. what is the integrative aspect of the material, how are computing systems integrated with sustainability, etc.), guidelines (i.e. are there any concrete activities, steps, evaluation mechanisms, standards for the learners to work on, etc.) and discipline (relationship between the material, sustainability and the specific discipline the material aims to support). Next, they applied these questions on a set of materials available to them and provided specific detailed examples on how would assess them. The authors also proposed that the evaluation mechanism be adopted by ACAM as the building block for a repository of resources to support green IT curriculum. Beyond the elegance in the design of the

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assessment mechanism, the report again emphasizes the lack of resources: the working group evaluated only 14 materials, many focused on more general concepts of conservation and personal responsibility. Moreover, no evidence was found by us that the working group's recommendations were adopted by ACM or that a repository of resources exists elsewhere. A collection of materials is also provided in [6] although no evaluation of these resources is provided. The list does include several recent publications such as Tomlison's book on greening through IT [8] and a study exam on green IT certification [9].

The ambiguity of academic institutions to introduce green IT focused offerings, is emphasized in the institutional survey [6] where many survey respondents express reservations that the administration will support the development of full degrees. The solution is thus for individual instructors to design specialized courses or to integrate sustainability topics in existing courses. Initiated by Cai in [10], the curriculum integration is further discussed by Mann and Smith in [11]. Mann argues that a significant challenge remains the ability of standard initiating authorities (such as ACM) to promote sustainability. In reviewing the current computer curriculum program standards, Mann argues that sustainability is not explicitly mentioned in the documentation. Faced with constraints on the number of credits allowable by many institutions, the development of green standalone computing courses is thus difficult. Based on this we suggest that a modular approach (as suggested by Cai [10]) where sustainability modules are included in existing courses is advisable.

Such modules have been already proposed. In [12] the concept of sustainable software is discussed at large. In [13] a sequence of modules that can compose a full course or be used in separate classes is discussed. However, such modules are usually incorporated in higher level courses. Often, student's attitudes towards a topic are shaped early on in their academic life. Based on this assumption, we suggest that sustainability modules can be included in their first college courses. The authors of [14] suggest the same, although no concrete discussion of their education approach is presented.

In this paper we propose a sustainability module we developed for an introductory computing course. We start by providing a justification of our work, motivated by the students' attitudes towards green IT as emphasized by an initial study. We continue with a description of the module and the class it was prepared for. Finally, we analyze the impact the module had on the students by discussing the results of an assessment survey.

II. STUDENTS' VIEW

In May 2010, we designed and administered a survey on the "computing" behavior of the students. The survey included 20 questions, with approximately half of them focused on identifying the type of devices used by the students (form factor, brand, age, energy efficiency). In addition, questions on student's computing use (such as preferred computers used in campus, number of days the student spends in campus, awareness of and attitude towards Energy Star rating systems, etc.)

Two separate groups of respondents were targeted. The first group (identified in the discussions as *2010 Non-IT*) was formed of non CS/IT students taking an Introduction to Computing course. This course is provided by our University as the main avenue to satisfy the computer fluency component for the General Education Curriculum. The course has two primary objectives, a) to enable students to use current office software products (word processor, spreadsheet, presentation software, database systems) efficiently, and b) to enable students to understand fundamental concepts of computing, as well as current issues in computing and the impact of computing on society. The survey was answered by 137 students taking the course. Since the course does not satisfy any requirement for our computing programs, all respondents were non-computing majors with most indicating social science or humanities background. Being an introductory course, most respondents were freshmen (39%) or sophomore (34%) with a minority being junior (20%).

The second group (identified in the discussions as *2010 IT*) was formed of Information Technology (IT) and Computer Science (CS) majors enrolled in a Computer Science II type course. The course provides in depth coverage of data structures, algorithms and syntax using an object oriented programming language such as Java or C++. Forty seven students answered the survey. The majority of the students (70%) were IT majors, with the balance formed of CS majors (14%) and other disciplines (16%). Since the course has at least one prerequisite, many students take it starting with the second or third semester. Our program also accommodated a large number of students transferring from community colleges. Thus, when asked for their current academic year, the students identified themselves mostly as sophomore (21%), junior (36%), or senior (32%).

In connection with our computer sustainability module we administered parts of the survey again in Fall 2011. The 44 respondents are identified in the discussions as *2011 IT*. A description of the course the students were enrolled as well as demographic information is provided in the following section. Here we use the data only to see how the students' attitudes have changed a year and a half later as well as to see if any changes in technology use have occurred.

In trying to understand the student's attitudes towards green computing, our survey focused on basic topics such as system usage and user awareness. One question asked whether the students' computer system has the Energy Star rating label. The rating was introduced in the US by the Environmental Protection Agency (EPA) also has equivalents in Europe and elsewhere. It evaluates the energy efficiency of most devices powered by electricity [15]. Computing systems are now currently assessed under the 5Th standard [16]. Devices that satisfy certain energy efficiency criteria are allowed to prominently advertise it through a standardized logo. While no industry wide assessment on the number of Energy Star rated devices is found, a survey of the main manufactures sites show that the aim is have most devices bearing the label (Apple claims all its products meet

the rating, while Lenovo and HP indicate that over 90% of the laptops and over 50% of their desktops also meet their rating)[17-19]. As such, the expectation for the systems used by the students is to see a majority of them being Energy Star rated. Fig. 1 provides a summary of the responses. We see surprisingly that most of the respondents indicated that their system does not have the rating or that they are unaware of such rating. Looking at the age of the systems (Fig. 2) we see that the majority of the computers used by the students is 2 years or newer (thus most probably falling under Energy Star rating). Moreover, as consistently approximately 80% of the respondents in each group indicated that they use laptops; such assessment is at odds with manufacturer's claims that their full lines of laptops are Energy Star.

The discrepancy in results can also be attributed to the students' inability to determine if their systems have the rating. Indeed, when comparing the IT and non-IT respondents in 2010 we see that the age of systems used by both groups is relatively the same. Yet, the IT majors report both better energy ratings for their systems as well as increased ability to identify the presence or absence of rating. The computing major's interest on the issue as well as the experience acquired by taking multiple computing courses could be the factors that lead to better ability to identify their systems' performance. Such reasoning supports our argument that sustainability modules are relevant to introductory courses. Learning about the impact computing has on the environment would support the students drive to become environmentally conscious and also make them receptive to additional sustainability topics in the future.

As indicated, our survey also included questions on the day to day behavior of the students (such as whether they use personal systems at school, for how many days/hours, etc., what are the preferred computing activities, etc.). While discussing these results goes beyond the purpose of this paper we point to Fig. 3 that shows the student's preference to bring their systems at school, and if so if they charge their system at school. We see that more than half of the students bring and charge their laptops at school (slightly higher for IT majors). An empirical survey of the classes allocated for our programs revealed that while the number of seats varied (with the smallest being 25 seats), the number of power outlets was usually constant (and significantly lower than 12). When also considering that energy consumed through these outlets is not traditionally considered to be part of the IT footprint, we see another incentive on the need for green computing to be integrated in our curriculum.

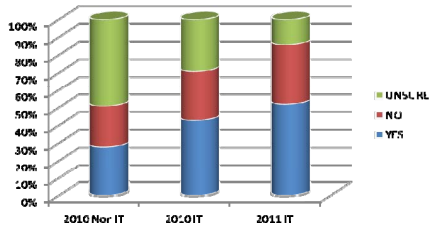

Figure 1. Answers to the question whether the computing system is Energy Star efficient.

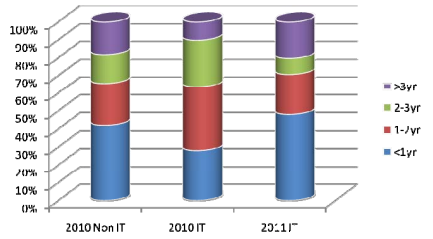

Figure 2. Age of the computing systems used by survey respondents.

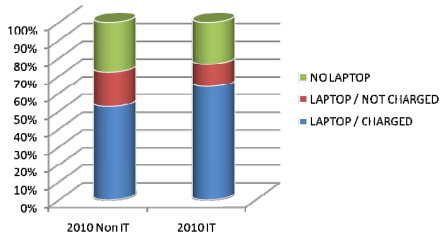

Figure 3. Answers to the question whether the students bring and charge their laptop at school.

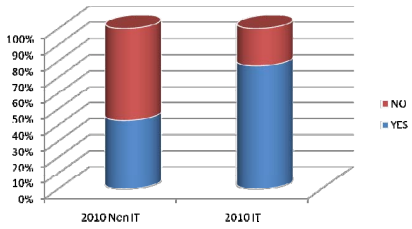

Figure 4. Answer to the question whether green computing be included in your curriculum?

Finally, we described to the students the concept of green computing and asked them if they consider that it should be integrated into the courses they are taking. Fig. 4 provides a summary of their answers. As expected, the computing majors have a stronger preference towards this inclusion.

III. Introducing Green IT in the Classroom

Our university is a medium to large institution in United States with about 18,000 students offering over 100 undergraduate degrees, tens of MS programs as well as six doctoral programs. The Computer Science department offers programs leading to Bachelor of Science in Information Technology and Computer Science as well as a MS in Computer Science. Currently the number of undergraduate majors is close to 300, with 60% in the IT program and the balance in the CS program.

When considering what is the best approach to discuss green computing in the classroom we aimed to have the biggest impact possible on the student's future profession. As such, we focused on an introductory course required to be taken by all our IT majors. The course provides an overview of the concepts of information technology. It discusses principles of computing, Internet and office application software, hardware and networking components, the role of

IT in an organization, legal and ethical issues of computing, etc. Compared to our General Education offering, the course, emphasizes the profession of IT and focuses more on fostering IT specific skills such as programming or algorithmic thinking. The enrollment in the course is usually 40-50 students each semester with the majority being IT majors or undeclared.

In Fall 2011, most (75%) of the students enrolled in the course were IT majors with additionally 6% CS majors. The balance was formed of undeclared or other majors. As our program requires the student satisfy a certain math prerequisite structure often students declare their major late in their degree. With respect to their years of college, the students were evenly divided among all four years. The split is explained by two factors. First, our program also accommodates a large number of transfer students. Many of them join the institution with at least 2 years of coursework and declare themselves as juniors or seniors, even if they have two or three years left in their degree. Second, while this is a required introductory course, in the current format it does not serve as prerequisite to any other course in the degree, and as such some students select to take it later in their studies. The department is currently working on curricular changes that would make this course as first one in the program structure, and as such we expect the proportion of first year students to increase significantly.

Our module is formed of two distinct components, one focused on traditional presentation / lecture, and one on hands on activities. Both components were delivered in a traditional instruction format (in class), however, they can both be ported to a virtual environment.

The presentation component focuses on several aspects of computer sustainability (see Fig. 5 for summary of the topics). A complete set of materials (slides and external references) is available from the authors. For each section (A-E) we provided several supporting materials and case study discussions, in an effort to stimulate the student's deep learning [20].

A. Computing sustainability
- What is sustainability?
- Implications of sustainability on our lives
- What is computing sustainability?
- Measuring computing impact
- Carbon footprint

B. Assessing computing costs (Activity 1)
- Energy Star Rating
- Product Lifecycle

C. Computer hardware (Activity 2)
- Personal products
  - (Apple environmental policy, cell phone towers in Africa, etc.)
- Servers
  - (HP environmental policy, IBM servers, Google data centers)

D. Computer software (Activity 3)
- Search Engines
  - (Cost of Google search)
- Other application

E. Computing as a factor for change (Activity 4)
- Applications supporting sustainability
  - (mapping software,
- Communications
  - (virtual societies, telecommuting. etc.)

Figure 5. Topic structure for the sustainability module.

Activity 1.
- Present a list of costs associated with a tablet system (say iPad)
- Consider as many aspects of the device as possible (hint: not just its use)
- How do we come up with a value?

Activity 2
- Consider a regular laptop system. List three components that you believe are responsible for most of the energy loss through heat.

Activity 3
- Consider the concepts of cloud computing and virtualization
- What advantages do you see through this method? (at least three ideas)
- What concerns you in cloud computing? (at least three ideas)

Activity 4
- Identify three approaches through which you believe computing has supported our efforts to reduce the human carbon footprint.
- Name three computer applications that help you reduce your footprint. Explain briefly.

Figure 6. Activity structure for the sustainability module.

Each of the sections B through E had an accompanying activity that preceeded it (see Fig. 6). For each activity, the students had to work in teams of two-three and provide written responses. The instructor also discussed several responses in the class. The student's learning is thus facilitated by individual and team based investigation [21]. Often, the students responses reflected their understanding of the topics. For example, when asked to estimate all costs associated to a portable system (Activity 1), most teams provided the response from the point of view of the user (such as purchase cost, cost to rechanrge it, etc.). Even when prompted to consider the full life cycle of the product only few considerred packaging or transportation costs, fewer the cost of the service and repairs, and none the cost of discarding the product. Following this discussion, an analysis of the way Apple presents their sustainability efforts (including the full life cycle of the products) was provided.

IV. EVALUATION

We have administered two surveys as follow up to the green computing module. In the first, we have looked at the student's computing system's usage as well as asked them whether they believed that green computing is relevant to their professional preparation. With respect to the students' computing preferences, we see that the 2011 majors use slightly newer systems (see Fig. 2). The students have also a better understanding of Energy Star ratings with only 14% indicating lack of awareness on whether their system is rate. We also note that the systems used are predominantly energy efficient. To test the understanding of various concepts discussed in the module, the students were asked to define the carbon footprint (81% answered correctly), and to provide a description of green computing (80% provided a reasonable description). When asked whether learning about

green computing is essential to their education as future IT professional, the students agreed (*M=4.13* on a five item scale where 1 is strong disagree and 5 strongly agree).

In a second survey we evaluated the students' experience with the computing sustainability module. The students were asked several questions focused on their learning experience. Each question was formulated with answers on a 5 item Likert scale where 5 means Strongly Agree and 1 means Strongly Disagree. Below we provide a summary:

- The activity was useful to me (*M = 4.17*)
- Most of the topics covered were new to me (*M = 3.38*)
- I feel I have a better understanding of the impact computing has on the environment (*M = 4.75*)
- The slides and activities provided for this topic were appropriate (*M = 4.50*)
- I recommend that this activity be maintained in future offerings of this course (*M = 4.42*)

The students' feedback indicates that the activity was positively viewed. The students' self evaluation indicates that they see themselves with a better understanding of the sustainability aspects of computing. In open ended questions, the students also expressed interest in learning more about sustainability, especially on how to accurately assess the carbon footprint of an IT product or the legal and ethical implications of sustainability for IT organizations.

V. CONCLUSION

Current climatic changes are pushing our society towards a way of life where concern for conservation of resources will play a crucial role. The ever expansion of IT solutions, facilitating communication, improved work performance, changing social dynamics and information delivery means that IT organizations will only increase their visibility on the global scale. As such, being aware how IT can impact on our planet's resources and how computing solution can be redesigned to reduce their impact will only increase in importance among the tasks charged of our IT professionals. Providing them with the background and practical skills to handle computing sustainability is thus an ethical responsibility for today's educators.

Our work provides an analysis of the current state of the art on the educational efforts to introduce green IT into the computing curriculum. Beyond a systematic literature review we also analyzed the students' perception on green IT and their day to day computing habits. We then developed and implemented an educational module aimed at beginning IT students that has received strong supportive feedback. Our work provides a stepping stone for innovative integration of sustainability in computing by motivating students to become responsible global citizen and professionals.

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