Computing and Sustainability: Evaluating Resources for Educators

Samuel Mann
Otago Polytechnic
Dunedin
New Zealand
+642
smann@tekotago.ac.nz

Logan Muller
Unitec Institute of Technology
Auckland
New Zealand
+6498154321
lmuller@unitec.ac.nz

Janet Davis
Grinnell College
Grinnell
Iowa, USA
+16412694306
davisjan@cs.grinnell.edu

Claudia Roda
The American University of Paris
Paris
France
+33140620682
croda@aup.edu

Alison Young
Unitec Institute of Technology
Auckland
New Zealand
+6498154321
ayoung@unitec.ac.nz

ABSTRACT
Computing has a significant impact on sustainable outcomes and computing education for sustainability has previously been identified as an important goal. This paper aims to address a barrier to the integration of sustainability into computing teaching – that of a perceived paucity of resources. The "framework" (Computing Education for Sustainability, CE4S) is developed that could be used by educators to access resources for the integration of sustainability in the computing curriculum.

Categories and Subject Descriptors
K.3 [Computing and Education]

K7.4 [The Computing Profession]: Professional Ethics

General Terms
Computing, Sustainability, Management, Economics, Reliability, Human Factors, Legal Aspects.

Keywords
Sustainability, Practitioner, Teaching philosophy, Education

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1. INTRODUCTION
Computing educators are increasingly interested in in issues related to social and environmental sustainability. Yet, this interest is confronted with barriers that significantly reduce the adoption of sustainability principles and practices within the computing curriculum.

These barriers, which maybe either perceived or real, include: (1) the computing educators' limited knowledge about sustainability issues, (2) the feeling of some that computing may not play a significant role in social and/or environmental sustainability, (3) the lack of, or poor accessibility of, resources for the integration of sustainability in the computing curriculum.

This paper describes the development of a "framework" Computing Education for Sustainability (CE4S), which could be used by educators to access resources for the integration of sustainability in the computing curriculum. It is designed with the objective of addressing the third of these barriers – that of poor integration of resources - by creating a structure that could be used by educators to identify resources that meet both the need of computing curriculum and also sustainable practices.

1.1 Background
Recent reports have helped cement the need for sustainability to be integrated as a core value into our teaching practices. The 2005 Millennium Assessment report by the United Nations [22] and the 2007 Intergovernmental Panel on Climate Change (IPCC) [9] both call on institutions to take urgent and radical action. Both reports agree that the ecological situation and its impact on humanity and life systems on earth had been grossly underestimated.

Many institutions have rallied to this call. John Vig, President of IEEE, in early 2009 created the "President's Sustainability Initiative" to "contribute IEEE's expertise to the public dialog and to strengthen IEEE's societies' efforts and capabilities in the field" [23]. Vig is quoted as saying "I see sustainability as a major issue of the millennium, one that's of increasing interest to society as well as to IEEE members. It involves many, many issues, including political, economic, and technological. Where IEEE can help is in technology." Within the ACM, the keynote address of the 2007 SIGCSE conference by Ed Lazowska made it clear that the next frontier, and perhaps the most urgent and challenging for computing, is sustainability. "Computing is enabling a transformation of all areas of science and nowhere is this more critical than in the area of sustainability: There is no more important problem than our environment - this is the space race for today's generation" [12].

The tertiary education system is also responding, some in bold and well-defined initiatives. RMIT University, School of Business IT in Australia, has set up a dedicated resource called the "Green IT Observatory" in which academics can submit and find resources specifically on sustainability[19]. "The aim of the Green IT Observatory (GITO) platform is to promote research collaborations and the sharing of knowledge between and among practitioners and researchers". Otago Polytechnic [18] in New Zealand, has committed to "doing the right thing" as a key organizational value. The implementation of this initiative is to have every graduate holding sustainable practice as one of their key values. They have developed the concept of graduates being "sustainable practitioners". The multinational Southeast Asian postgraduate institute, the Asian Institute of Technology (AIT) [1] in Thailand, has boldly embraced the challenge of ecological degradation caused by human action in the President's decree "education and research towards the sustainable development of the region, strengthening the knowledge, development and business capacity of the region, and supporting communities and their economic development and integration into the global economy". All areas of education within the institution must equip students with the tools, attitudes and values required to make the shift in behavior required for the mitigation and adaptation to the challenges of climate change.

Whilst a major concern remains that the number of education institutions and indeed governments embracing these challenges remains alarmingly low, we are seeing grassroots movements coming from a multitude of sectors facilitating change. Hawken, who has studied this movement, refers to it as "a movement akin to a biological immunity" [7]. The immunity to which he refers is "a disease on earth caused by human exploitation of its resources". It is here that lays one of the challenges to pragmatically address and include issues of sustainability into entrenched teaching curricula, design and indeed attitude. The paradigms shift and change of mindset that six million organizations across the world are augmenting is increasing the pressure on those in the post secondary system to embrace sustainability as core values of the subject and discipline areas.

There are three main approaches that can be used in order to address sustainability issues within the curriculum.

- A *centralized* approach would concentrate sustainability-related subject matters in one or two courses addressing the many ways in which computing professionals may make a difference in social and environmental sustainability.
- A *distributed* approach would ensure that many different computing courses address sustainability issues, trigger students' direct responsibility, and demonstrate how the specific computing discipline may contribute to implementing or promoting sustainable practices.
- A *blended* approach would be to offer courses/programs focusing on sustainability whilst also having sustainability issues addressed across the curriculum.

Distributed and blended approaches seem the most suitable for "infusing" sustainability principles in the computing community and ensuring that every aspect of computing contributes to the implementation of sustainable practices. Such approaches, however, require adapting many different courses and therefore necessitate the active contribution and participation of a wide range of educators within the institution. Centralized approaches, although likely to be less effective, may be easier to implement within an institution that is first moving to include sustainability in the computing curriculum and maybe the instrument for the establishment of a leadership that will guide the implementation of the distributed approach.

The framework developed by this working group is explicitly designed to support decentralized approaches in two manners. It aims at providing educators with a tool that helps them in selecting existing resources for use in their classes and within the specific computing discipline. It also provides guidelines for the adaptation of existing resources to the computing curriculum and for the development of new resources.

At the 2008 Innovation and Technology in Computer Science Education (ITiCSE) conference in Madrid, Spain, it was identified that computing professionals acknowledged the need and willingness to do something about the collapse of our ecological systems but were struggling with specific ways of incorporating this into the teaching of computing [14].

From President Obama, to John Vig, to Ed Lazowska to John Hawken, the message is clear that computing plays a key role in this shift of mindset and practice. This message was endorsed by the computing professionals attending that 2008 ITiCSE conference. The question that now needs to be addressed is: how do we do this in computing education?

This working group paper is designed to address the issue of how we can help computing educators incorporate the values of sustainability into computing education, and the mindset of measuring impacts of computing systems in terms of ecological and social contexts in timeframes that extend past the next financial quarter and into future generations.

In this paper we sampled existing resources that are being used by computing educators, we then developed a framework based on internationally recognized benchmark frameworks to give a pragmatic tool by which computing educators can assess and augment resources for integration into their curriculum areas. When we sampled existing teaching resources we found that there were some significant gaps. The first was that resources are not in forms ready yet to be used in the classroom so require some form of adaptation or framing to suit the level or particular discipline. A further gap, is that none of the resources we evaluated rated highly on all aspects of the rubric; resources will need to be combined or augmented to adequately address sustainability issues in the CS curriculum.. These gaps are described in the following sections.

1.2 Framework development

The framework was designed with the objective of creating a structure that could be used by educators to access resources for the integration of sustainability in the computing curriculum.

We developed the framework using an iterative process: brainstorming, categorization, synthesis, and group and individual application of the framework leading to further refinement.

The process began when one member of the working group posed a scenario to prompt individual brainstorming: "Suppose a colleague asked you whether you would recommend the book Green Operating Systems for teaching an undergraduate operating systems class. What questions would you ask in evaluating that resource?" Each of the five working group members generated five to ten questions for evaluating the imaginary Green Operating Systems textbook. We each read out our questions to the group, noting similarities amongst then, and wrote abbreviated versions of the questions out onto sticky notes. We repeated this process for Software Engineering, a class with which most of us are familiar. We then repeated the process with the course most dissimilar and seemingly unrelated to sustainability that we could think of: Theory of Computation.

During the brainstorming process, we posted sticky notes representing questions for evaluating resources to the wall, grouped by course. After brainstorming was complete, we collaboratively grouped the sticky notes into thematic groups and generated labels for the groups: Philosophy of Sustainability, Sustainable Practice Theory, Sustainable Practice Guidelines, Integrated Curriculum, Case Studies, and Discipline-Specific Questions. Some ideas were difficult to fit under a particular label; we used the two-dimensional space to show how those ideas fit between two groups. Ultimately, we drew a working diagram of the relationship between the seven themes, the interaction of the areas leads to the theme areas (Figure 1).

Later, the group synthesized the sticky notes under each theme into a smaller set of question. Teams of two or three members further discussed the original sticky notes and the synthesized questions. The questions were further distilled and re-categorized, combining redundant questions, until each theme had between two and five associated questions. These themes and questions comprised the first draft of the framework.

As a group, we applied the draft framework to two disparate resources in order to test and further refine the framework, and to come to a consensus on the interpretation of the questions. The first was a Business Week article titled, "Dell Aims to Go Carbon Neutral," [8] which has been used as an example in a computer ethics course. In applying the framework to this first resource—very different from the textbooks we imagined in our brainstorming scenario—we rephrased some of the questions. We decided that a binary yes/no was insufficient and moved to a 4-point scale.

1. Not at all
2. Somewhat
3. Mostly
4. Thoroughly

Finally, we realized that it was important to include justifications of our ratings for our own process of refining the framework. We identified a second resource that was deliberately dissimilar from the first—Anja Mursu's [15] lecture notes on "IS design and use in developing nations", and collaboratively applied the framework to this second resource, making no further changes to the framework.

Members of the working group each applied the resulting second draft of the framework to two further resources each, ten in total.

One of the issues that need to be considered is that we were looking at computer science from a perspective of sustainability. Sustainability as a topic and sector has received much attention and indeed discussion. The reports from the United Nations and others refer to in the previous section indicated the need to have a more structured approach in framing sustainability initiatives. It was felt it was prudent to benchmark our framework against those that are internationally recognized in other areas.

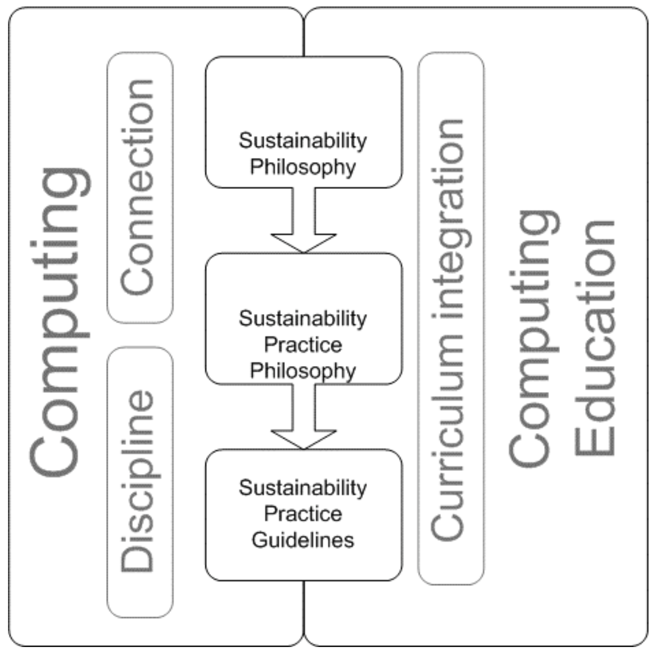

Figure 1: The Computing Education for Sustainability framework places sustainable practice at the nexus of computing and computing education.

2. Framework structure

The current draft of the framework consists of twenty-three questions grouped under six themes: Sustainability Philosophy, Sustainable Practice Philosophy, Sustainable Practice Guidelines, Curriculum Integration, Linking and Connection, and Disciplinary Issues.

For each theme a set of questions guides the assessment of existing resources towards establishing if and how the overall theme is appropriately addressed, and/or how the resource could be expanded, or integrated with other resources, to achieve appropriate theme coverage. The questions are shown in Table 1.

The first area, philosophy, addresses the overarching ideas of computing for social and environmental sustainability (following a strong sustainability approach) as shown in Figure 2. We assume that any resource should be grounded in a, possibly partial, understanding of the significance of sustainable practices, their relevance to the computing profession, and the individual professionals' responsibility to the future generations.

Table 1: The Computing Education for Sustainability framework questions

Philosophy

1. Does the resource reinforce computing as a pathway or tool for achieving sustainable practices?
2. Does the resource implicitly or explicitly define sustainability in a way the student can understand?

Practices

1. Does the resource demonstrate a clear relationship between sustainability and computing?
2. Does the resource support a holistic approach to the evaluation of costs and benefits, accounting for invention, implementation, use, reuse, and disposal?
3. Does the resource encourage adaptation of existing hardware/software systems to the needs of sustainability, rather than reinventing the wheel?
4. Does the resource help students appreciate the needs of all involved stakeholders?
5. Does the resource encourage a system approach to sustainability (e.g., considering issues of feedback, control, multiple scales, and iterative design)?

Guidelines

1. Does the resource provide a framework of practical steps or methods to address sustainability within the discipline?
2. Does the resource address policies, standards, guidelines, or evaluation criteria related to sustainability in the context of the discipline?
3. Does the resource suggest a change management approach by addressing the impact of the deploying new sustainable practices/hardware/software (e.g. technology adoption model)?

Curriculum integration

1. Does the resource fit into a standard disciplinary curriculum, covering either a focused or comprehensive curriculum area?
2. Can the resource easily be adapted to fit into the context of the courses?
3. Is the resource well written and appropriate to the students' level (e.g. undergraduate, graduate, non-major)?
4. Does the resource include questions, problems, projects, or case studies to engage the students in thinking about the discipline in the context of sustainability (or vice versa)?

Linking and Connecting

1. Does the resource provide a clear pathway where the discipline can be linked to social or environmental sustainability (e.g., carbon footprint, ecology enhancement, social equity)?
2. What are the specific areas of sustainability that the resource can be linked to (e.g. CO_2, electricity use, energy use, social issues, ecology)?
3. Can a definite ecological/social impact or consequence be identified, whether positive or negative?
4. Does the resource encourage students and practitioners to see themselves as directly responsible for sustainability?

Discipline

1. Does the resource address current practices and challenges related to sustainability in the discipline?
2. Does the resource address the sustainability impact of typical design choices related to the discipline?
3. Does the resource indicate specific areas of the curriculum to which sustainability is particularly relevant?
4. Does the resource provide a conceptual framework for understanding sustainability issues in the context of the discipline?
5. Does the resource make a clear distinction amongst the different meanings of "sustainability" used in the discipline (e.g., social sustainability, environmental sustainability, sustainability of the software system itself)?

The second theme, sustainable practices, addresses the issue of best sustainable practices within the computing discipline. It broadly looks at how a resource may be used to encourage those practices by clearly stating the relationship between sustainability and computing, promoting a system approach and holistic evaluations of cost/benefits throughout the lifetime of computing artifacts, supporting re-use strategies whenever appropriate, while addressing the needs of all stakeholders including future generations.

The third theme, guidelines, aims at ensuring that the resource provides students with an insight on how to implement the specific practices. It calls for direct references to policies, standards, evaluation criteria, and in general practical steps and methods within the specific discipline. This theme also addresses guidelines to technology adoption and change management practices.

The fourth theme, curriculum integration, deals with the level of integration of the resource with the existing computing curriculum. Resources may treat sustainability issues within the framework of very specific curricular items (e.g. the topology of a sensor network) or they may cover a larger curricular area (e.g. is ubiquitous computing really environmentally sustainable?). Some resources may also be easier to integrate in the existing curriculum than others, they may be more suitable for students at a certain level (e.g. undergraduate), or provide suggestions for assignments such as case studies, exercises, and students projects.

The fifth theme, linking and connecting, is aimed at supporting the analysis of how well the resource links sustainable philosophy, practices, and guidelines, to the computing curriculum and the individual disciplines. It looks at how the resource relates social and environmental sustainability to computing ensuring that impact, as well as responsibility, are identified.

Finally the sixth theme, discipline, looks at how well the resource fits a specific discipline whilst appropriately covering sustainability issues. In each one of the questions in this section the word "discipline" should be replaced with a specific discipline name to obtain questions such as: "Does the resource address the sustainability impact of typical design choices related to human computer interaction?", (question 2 adapted to "human computer interaction").

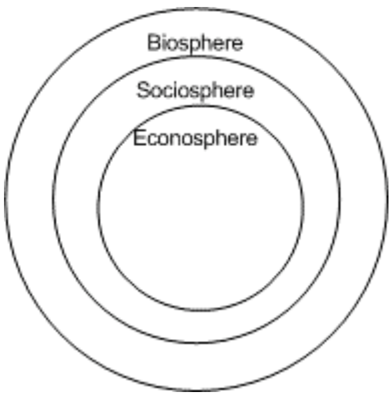

Figure 2: Strong sustainability

2.1 Current resources

The working group was motivated by a desire to provide resources for computing educators to include sustainability in their curricula. A logical place to begin was to find sustainability resources already in use by computing educators.

Resources were obtained by the following means:

1. An email to the AIS and SIGCSE-discussion mailing lists asked computing educators to submit resources they had used or considered using in their courses. This request resulted in responses from seven computing educators.

2. We examined resources in use in a few existing courses and programs on computing and sustainability.

3. We sampled resources in areas we found of interest, including pervasive computing and human-computer interaction.

Our sample of resources related to sustainability and computing is a convenience sample, including those who replied to our email and programs and resources we knew about. Our sample is not exhaustive—there may be many resources we did not find, but we believe it to be reasonably representative. In addition to these "sustainability" resources, we also used the framework to examine standard computing texts. The resources are shown in Table 2.

Within the CE4S framework we have chosen to analyze resources only along aspects that are specifically related to sustainability, in the discussion section we indicate how, in the future, our framework could be integrated in existing structures of other pedagogical resources.

3. Results

The full results are shown in Appendix 1. Here we explore the application of the framework to three example resources.

Table 2: Resources used in assessment of CE4S framework

Dell Aims to Go Carbon Neutral	News story	CO2, energy
IS design & use in developing nations	Lecture notes	social issues, poverty, digital divide
The last hours of Ancient Sunlight	Book	social, CO2, ecological, energy, cultural
Harnessing Green IT: Principles and Practices	Magazine article	CO2, energy use, ecology
Expected Environmental Impacts of Pervasive Computing	Journal article	electricity use, ecology, use of fuel and metals
Interaction design for rural agricultural sensor networks	Workshop paper	agriculture, literacy, digital divide
Informative Smart Green Office Buildings	Workshop paper	electricity, energy use, ecology
Green IT Diffusion: An International comparison	Working paper	CO2, energy
A preliminary report on Green IT attitude and actions among Australian IT professionals	Working paper	CO2, energy
Six Sins of Greenwashing	Report	social issues
Ethical and Social Issues in the Information Age	Textbook	social issues, digital divide
A Gift of Fire	Textbook	Pollution, ecology
Interaction Design: Beyond Human-Computer Interaction	Textbook	Water use
The Designer's Atlas Sustainability	Textbook	Holistic impact of professional activity

3.1 Example application: Green IT

Murugesan [16] in the paper, "Harnessing Green IT: Principles and Practices," gives an overview of Green IT for IT professionals. The article motivates "Green IT" by discussing environmental impacts associated with IT, along with the benefits of "greening IT." After identifying four areas of concern—use, disposal, design, and manufacturing—the article presents environmentally sound principles and practices in each area.

The article implicitly defines sustainability as minimizing environmental impact, including CO2 emissions, use of raw materials, and hazardous waste—a definition students can readily understand. Although the article mentions several ways in which computing can contribute to more sustainable practices, computing is discussed mainly as a source of harms to be mitigated. The article clearly links IT with sustainability; its focus is on promoting principles and practices for minimizing environmental impacts throughout the IT lifecycle, including reuse and adaptation of existing hardware. Although the article accounts for businesses that both use and manufacture computers, it considers no other stakeholders, thus earning a 1 ("slightly") for this question. Systemic effects or future generations are also not accounted for in this article.

The article also addresses change in practices and thinking, but in a fairly concrete and limited way. It provides many practical steps (e.g., "turn off the system when not in use") and some principles (e.g., "reuse, refurbish, recycle"), but not a method for assessing business practices as a whole or introducing new practices not explicitly discussed in the article.

The resource could fit into several areas of the curriculum, including classes on computing and society, operating systems, and computer architecture. Because this article is aimed at a business audience and assumes relatively little technical knowledge it should be accessible to undergraduates. For classroom use, the educator will need to augment the article with learning activities appropriate to the students' level that explicitly connect the concerns raised in the article with the technical content of the course.

With respect to linking and connection, the article clearly links IT with environmental sustainability, focusing on CO2, energy use, and ecology. It identifies specific negative environmental impacts of computing, and gestures towards opportunities for positive influence. Students are clearly made responsible: "let's focus on what each of us—as IT professionals, members of the IT industry, and IT users—can do individually and collectively to create a sustainable environment" (p. 25).

With respect to the specific areas operating systems and computer architecture, the article addresses at a high level, current practices and challenges related to sustainability, and certainly illustrate the environmental impacts of typical design choices. It indirectly indicates relevant curriculum areas, such as virtualization in operating systems, and provides somewhat of a conceptual framework for understanding sustainability issues in IT. The article considers only environmental sustainability, and not other senses of sustainability that might be relevant to IT.

3.2 Example application: Pervasive computing

Kohler and Ermann [11] analyze systemic effects of future pervasive computing systems on the environment. They consider multiple scenarios for possible future development and uptake of pervasive computing, at three levels of analysis: first-order effects, notably the negative environmental impacts of manufacturing, using, and disposing of the computing devices themselves; second-order effects, the positive changes to culture and practice resulting from pervasive computing use, such as increased telecommuting and more efficient use of fuel; and third-order or rebound effects, which occur when growth in demand for a resource overcompensates the savings from second-order effects. The paper then concludes that there is too much uncertainty to quantify the environmental impacts of pervasive computing. Policy should promote the second-order benefits of pervasive computing for environmental sustainability while accounting for the risks.

In considering second-order effects of pervasive computing, this article includes substantial information about computing as a pathway or tool for achieving sustainable practices; it defines sustainability in terms of material and energy consumption. The paper uses a holistic, systems approach in its analysis of the environmental impacts of pervasive computing, demonstrating a clear relationship between pervasive computing and sustainability. However, people are curiously absent from the paper, which is focused mainly on things and systems. Although the paper is about future technology development, it does little to focus students' attention on either current stakeholders or future generations.

As the paper is about analyzing the path of current research trends into the future, it provides criteria for evaluating the environmental sustainability of pervasive computing systems. It recommends the creation of policies regarding pervasive computing and sustainability, but does not propose those policies itself. The paper does not aim to provide concrete steps or methods for addressing environmental issues today.

The material in this paper could fit well into courses on pervasive computing, human-computer interaction, or computers and society; however, the article is not written for an undergraduate-level or even a graduate-level computer science audience. Most instructors would need to invest significant effort in obtaining background knowledge on environmental risk assessment, interpreting the article, and developing appropriate learning activities. The paper clearly connects the discipline of pervasive computing to sustainability; though it does raise the need for policy addressing these issues, it does not particularly encourage computing students and practitioners to see themselves as responsible for sustainability.

In considering first-, second-, and third-order effects, the paper provides a framework for considering environmental sustainability in the context of pervasive computing systems. It considers the current state of research and practice, directions future development might take, and the challenges thus posed. As a research article, the resource does not aim to fit into a particular place in a computing curriculum; it focuses entirely on environmental impacts and not other forms of sustainability.

3.3 Example application: Rural agricultural sensor networks

Walker, et al [24] in their paper on 'Interaction Design for rural agricultural sensor networks' describe "*the ongoing design of a sensor network for small family farms in rural Kenya. The sensor network is just one part of an 'ecology of resources' in which handheld devices are used to bridge the sensor network and a computer-based access point.*

We describe the two villages where the system is deployed and the user requirements collected. We then describe the architecture of the sensor network and detail how it fits in with the larger integrated system. We then detail our approach to interface and interaction design, and conclude by describing the next steps in the project".

This resource reinforces computing as a tool for achieving sustainable practices by presenting a concrete example of the use of computer applications to support local agricultural practices, promote literacy, and information literacy. Environmental and social sustainability are defined in the context of the specific project and community addressed.

The relationship between sustainability and computing is highlighted by the discussion of how local constraints impact on system design choices and by a careful study of the needs of all stakeholders. Many aspects of the computing system life cycle are analyzed including invention, implementation and use, and an informal cost/benefit analysis is proposed. The system proposed is built by adapting existing technology. Further considerations which are not explicitly addressed in the paper on scalability, reuse, and disposal of the system, could be added in as an in-class discussion.

This paper does not aim at providing general guidelines for the development of environmentally and/or socially sustainable computing systems but the case proposed may help understanding the practical steps involved in the process of designing such systems.

This resource could easily be used in a course on sensor networks and/or wireless/mobile systems. The paper also addresses interesting HCI issues but, because of its technical content related to sensor networks, it would only be suitable for graduate courses in this discipline (or it would need some introduction to some of the more technical parts). The paper provides a clear pathway where sensor networks can be linked to issues of ecology enhancement and social equity.

The sustainability impact of typical design choices related to sensor networks is one of the main foci of the paper (e.g. “the sustainability of the network requires minimal hardware cost and, ultimately, autonomous operation, since no technical expertise will be available for maintenance”, “deployment areas are typically large, requires scarce deployment of nodes in a large field”, “the radio range of the nodes should be large enough to guarantee connectivity”).

3.4 Original Examples Mapped to the Framework

The original two resources that were used when developing the questions and framework were then applied to the new framework and are shown in Figure 3. The top part of the figure shows the “Dell aims to go Carbon Neutral” given stars, one for each point, and displayed on the CS4E Framework diagram. The bottom part of the figure is the results for the “IS in Developing Nations” resource. To show the results in a different way they were also mapped to kiviat diagrams and these are shown in Figure 4.

3.5 Interpretation

Our hope is that the CE4S framework will help computing educators in selecting the most appropriate resources for their courses. The framework provides a clear indication of the resource coverage of sustainability issues and computing subjects, as well as evidence of how the two aspects are integrated. At this stage, we expect that few resources will score highly on all three aspects, however resources that have low scores in one or more themes of the framework may still be very useful. Most likely resources will be collected into bundles that provide students with an overview of all necessary aspects.

For example, Bray [2] offers the basis for creating a bundle including computing resources on visualization of sensor measurements, and sustainability resources on optimization of energy use within buildings.

Resources with low scores on curriculum integration and high scores in philosophy, practices, and guidelines may be well suited for a high level discussion about sustainability issues. This is the case, for example, of “Six sins of greenwashing” [20] which, although written for a marketing audience, can be easily adapted to introduce computing students to aspects of procurement and interpretation of marketing material. This type of resources will likely require discussion in class and may be integrated with more technical resources.

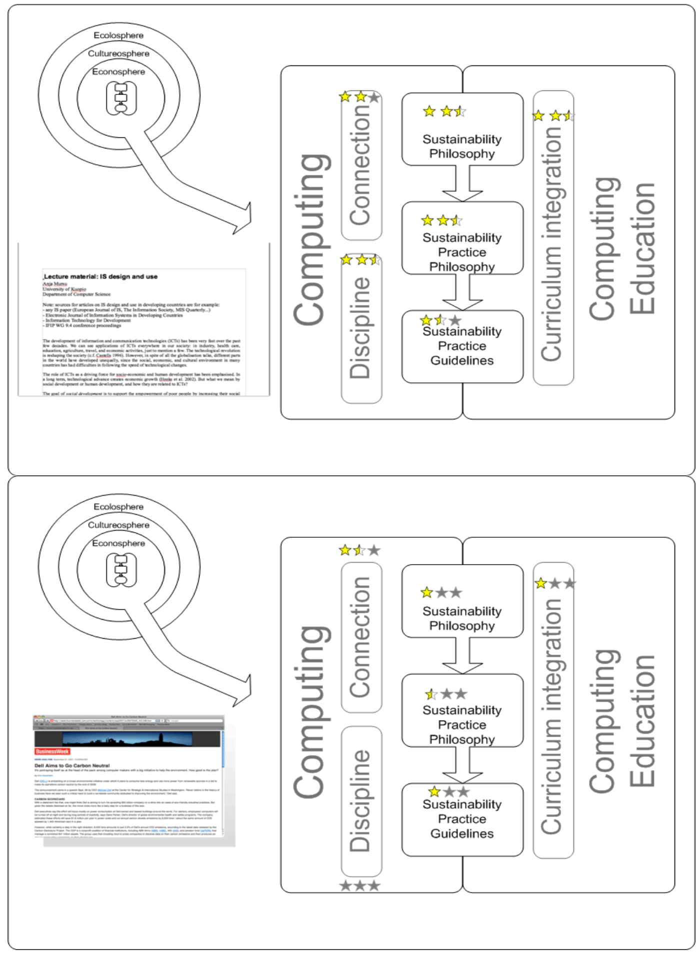

Figure 3: Two resources (Dell IT and IS in developing nations) considered against the CE4S framework

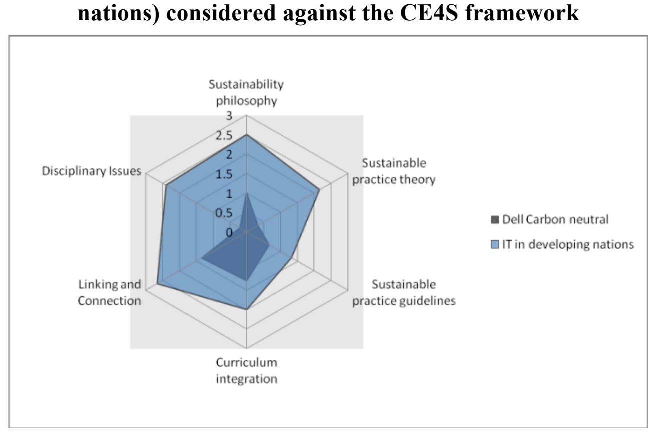

Figure 4: Two resources (Dell IT and IT in developing nations) considered against the CE4S framework as a kiviat diagram

On the other hand, resources with high scores on "curriculum integration" and/or "discipline", and lower scores in "philosophy", "practices", and "guidelines", may not offer a good coverage of sustainability issues and they may be integrated with resources that make up for this weakness.

We expect that resources of the first type, i.e. strong on sustainability issues, will be particularly useful for educators in computing disciplines who, given a strong sustainability core and a (possibly weak) link to computing subjects can, using their own expertise, augment these resources for use in the computing curriculum. This activity will result in the creation of new bundles as well as new resources that will hopefully be widely distributed within the computing education community.

Computing educators should read one or more of the benchmark resources in order to ground their understanding of sustainability. The educator will probably not want to require students to read these entire resources (except perhaps in the context of a course on Computing and Sustainability), but can choose appropriate selections or explain particular concepts as needed to augment the primary resources connecting computing and sustainability.

The three resources discussed in the beginning of this section were also mapped to the framework and then shown as a kiviat diagram in Figure 5, which illustrates where resources can be complementary.

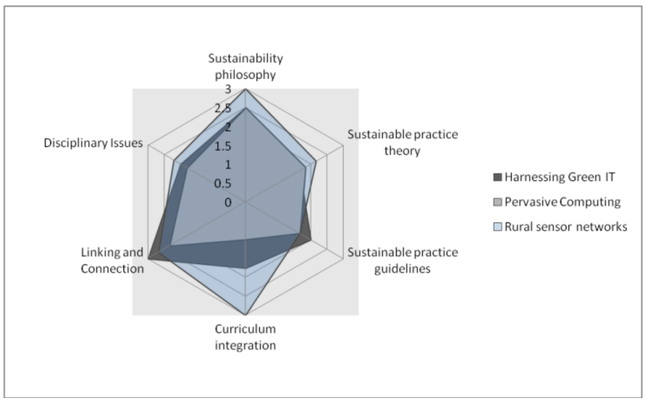

Figure 5: A set of resources may be seen to be complementary

As Figure 6 shows, Thorpe's "Designer's Atlas of Sustainability" [21] gives a much wider context to the narrow interpretation in some computing specific material. There, sustainable design is defined as "theories and practices that cultivate ecological, economic, and cultural conditions that will support human well-being indefinitely", a definition that does not exclude the activities of computing. While most of the examples are about traditional design, the contexts are either familiar (we all inhabit the world of design) or close enough to computing that the concepts would not be foreign to computing students. It was interesting to note that here are also some computing specific examples: Thorpe states that we are always multitasking, being in "a perpetual state of distraction" and being "pushed faster than our natural pace…resulting in a crisis orientation". The speed of technology is described as an "obstacle to cultural technology because it disconnects us…rarely is there a diplomatic pause for thought". There is also an interesting section on what designers could learn from open source – the possibility of "open artifacts" and every node being a point of both production and consumption.

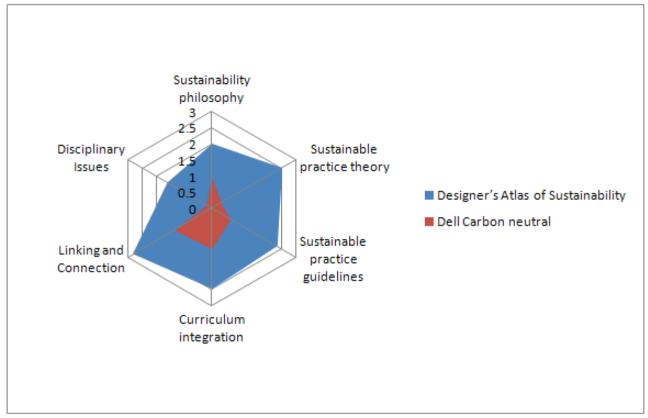

Figure 6: IT resources bolstered by sustainability material from a related field

4. Discussion

In developing the CE4S framework, we were cognizant of the technological frame of most of our backgrounds. The themes within the CE4S were informed by Wilber's [25] "the integral framework" for assessing the perspectives across a range of disciplines. These included business, psychology, politics, science, marriage, spirituality, religion and others. In the development of this framework he took the knowledge passed down by famous philosophers such as Plato, Buddha and Habermas and elaborated on their teachings from the perspective of the modern world. The three perspectives that dominated these great philosophers work was further divided, making them into four quadrants of perspectives. Wilber was the first to do this to move past what is commonly referred to in philosophy has "the big three". This is also referred to as I, We, and It. As systems perspectives became more understood it was Wilber who divided the It quadrant into "It" and "Its" with "Its" referring to the study of systems in any form that they take.

This framework was further developed by Brown [3] who applied it specifically to the field of sustainability. Figure 7 depicts the sustainability framework by Brown. The upper left quadrant refers to see "I". He refers to it and this example, as the psychological influence, that is the subject of all internal reality of the individual. This is how an individual views and react to any external behavior. The lower left quadrant is the "we" quadrant. Here Wilber calls this the quadrant of cultural influences. It is here where the societal expectations and the collective views and shared meaning of a group of people are considered or impact on an individual's actions. The upper right quadrant is the "It" quadrant, the objective or measurable influences that are normally quantitative in nature. Brown refers to these as the behavior of influences. Some refer to this quadrant as the measurable quantifiable influences that are the result of or, the influences a particular perspective or action.

It is the lower right quadrant however that Brown calls the "Its" quadrant that looks at the collective exterior Systems and environments. He calls it the "system's influences" and it is particularly important when we discuss sustainability. This is in part an important shift if we are using the quadrant approach as an analysis tool as the most significant and overarching system that we know of is the ecological often refer to as nature. When looking at actions and resources within a particular societal framework, such as computing, this quadrant becomes one of the most important. In Brown's analysis of sustainability resources, he found that the most common and popular writings over the last seven years have been predominantly lower right quadrant dominated. The reason for this has been the absence of the ecological systemic considerations in what has dominated the modern world's economic paradigms.

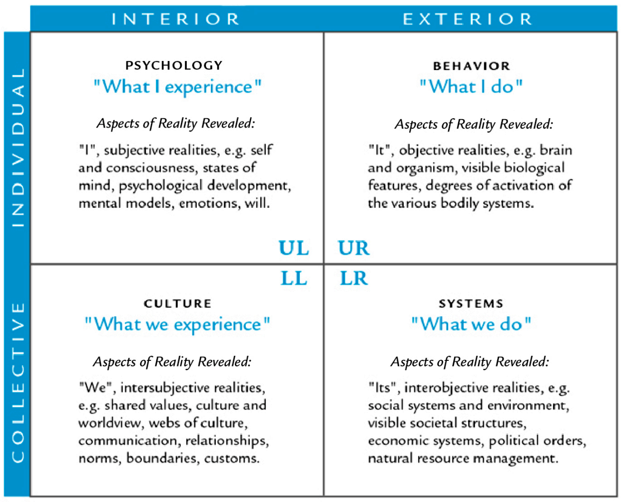

Figure 7: The quadrants are four unique, universal lenses with which to look at anything.

When we assess business and economic practices using either Wilber or Brown's integral analysis, we find that they have been dominated by the upper left, “I” quadrant and the lower left “We” quadrant. The pragmatic justifications and structures that build our social fabric are found in the upper right quadrant and merge as a framework to support what has developed as the personal and societal perspectives of progress, particularly over the last 150 years. Computing has been a major facilitator in the delivery, entrenchment and effectiveness of these upper right quadrant activities. These that collectively make up the first worlds economic system as described in McKibben [19]. As the framework for assessing sustainability was being developed, related resources in computing education provided a valuable basis to ensure that all quadrants are represented. Not doing so would give an unbalanced prospective on one or more of the quadrants. Hartman [6] points out “technology in particular has been an accelerant in achieving outcomes” dominated by the upper left in the lower left societal priorities. Using the framework and cross-referencing the resources on to Brown’s integral quadrant framework is a check against an accepted benchmark for ensuring an assessment tool does in fact reflect or four perspectives of humanity.

It was important to relate the new framework being developed for the specific purpose of assessing resources for use in computing education to a framework that is recognized within computing. As has been observed by Hartman, McKibbin, and Hawken the systemic approach of computing has been confined to the delivery of systems that are dominated or originate in the upper left all of the quadrants. The technological revolution has been dominated by the need to automate and streamline processes with the objective of "improving efficiency". Cash, Eccles, Nohria, and Nolan, [4] analyzed and documented this and referred to computing as having three main impacts of organizations and business practices. They were:

- 1 the ability to automate,
- 2 the ability to inform,
- 3 the ability to transform.

Chen, Bordeaux and Watson [5] took these earlier perspectives and looked at them in today's organizations in the context of our collapsing ecology. They discussed the need to transform business approaches and paradigms and to shift in attitude and conduct pass the mentality of doing the right thing by the environment by simply streamlining processes. They use the term “eco-efficiency” to embrace the historically accepted notion that using resources efficiently was of primary business and environmental importance. The term “eco-effectiveness” is used to frame the concept that computing has a priority role to play in ensuring our ecology is not destroyed in the pursuit of business. They discussed at length in their paper the need for institutional reform and a change in mindset. They see computing as having a major role in transforming the organizations into ones that not only respect but actually enhance our ecological systems.

As stated in the opening paragraph of the Joint Task Force for Computing Curricula 2005 [10]:

> *Computing has dramatically influenced progress in science, engineering, business, and many other areas of human endeavor. .... and those who work in computing will have a crucial role in shaping the future.*

5. Recommendations

The work on the CS4S framework was prompted by the desire of addressing the needs of the many computing educators who feel that tackling the social and environmental impact of computing within courses at all levels would enhance the quality of computing education. In order to address these issues, in a manner that reinforces the quality of individual courses without reducing the time allocated to standard subjects, the resources used must be well integrated within the computing curriculum, and be easily available to educators.

The framework proposed may guide educators through the evaluation (and possible enhancement) of resources, however we feel that much more could and should be done in order to:

(1) encourage a wide and "distributed" integration of sustainability subjects in the computing curriculum,
(2) help educators, who are interested or invested in social and/or environmental sustainability, but find it difficult to integrate its principles and practices in the computing curriculum,
(3) encourage the development of ad-hoc resources such as computing text-books addressing sustainability issues, and libraries of multimedia resources.

We see three main action actions that could be immediately addressed by the ACM.

First, the CE4S framework could be used to create an inventory of “computing & sustainability” resources to be made available to educators. A more extensive analysis of the available resources, as well as of the areas of computing best suited for the introduction of sustainability subjects, could guide a concerted effort in the development of further resources.

Second, the CE4S framework could be used as a basis to develop a meta-data structure addressing explicitly "computing & sustainability". Such structure could be integrated with other, more general, formal descriptions of learning resources see Nilsson [17], for a critical review of existing metadata standards in the field of teaching and learning. This would enable the automation of resources annotation, exchange, and retrieval.

Third, best practices for the introduction of sustainability issues in the computing curriculum should be studied through an analysis of the steps taken by those institutions that have already moved in this direction

It can be difficult for computing educators to assess how resources treat sustainability and sustainable practices unless they have some background knowledge about sustainability. Before assessing new resources, computing educators should read at least one of the benchmark resources described in this paper in order to obtain this background knowledge.

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Appendix 1: Resources assessed against CE4S framework

	Dell Carbon neutral	IS in developing nations	Harnessing Green IT	Pervasive Computing	Rural sensor networks	Green Office Buildings	Green IT Diffusion:	Green IT attitude and actions	Six Sins of Greenwashing	Ethical and Social Issues in the Information Age	A Gift of Fire	Computer Networks: A Systems Approach	Interaction Design:	Good Design Guide
Sustainability philosophy														
1.Does the resource reinforce computing as a pathway or tool for achieving sustainable practices?	0	2	2	3	3	3	2	2	0	0	2	0	1	1
2. Does the resource implicitly or explicitly define sustainability in a way the student can understand?	2	3	3	2	3	2	3	2	3	0	1	0	1	3
Sustainable practice theory														
1. Does the resource demonstrate a clear relationship between sustainability and computing?	1	3	3	3	3	3	3	3	0	0	3	0	1	1
2. Does the resource support a holistic approach to the evaluation of costs and benefits, accounting for invention, implementation, use, reuse, and disposal?	0	2	3	3	2	1	3	2	0	0	1	0	0	3
3. Does the resource encourage adaptation of existing hardware/software systems to the needs of sustainability, rather than reinventing the wheel?	0	3	3	1	3	2	2	1	0	0	0	0	0	2
4. Does the resource help students appreciate the needs of all involved stakeholders?	1	3	1	0	3	1	2	0	2	0	2	1	1	3
5. Does the resource encourage a system approach to sustainability (e.g., considering issues of feedback, control, multiple scales, and iterative design)?	0	2	0	3	2	1	0	0	0	0	2	1	1	3
6. Does the resource help students think about responsibility to future generations, who will deal with the consequences of the students' actions?			0	1					1	1	2	0	0	3
Sustainable practice guidelines														
1. Does the resource provide a framework of practical steps or methods to address sustainability within the discipline?	1	1	2	1	2	2	0	0	0	0	0	0	0	2
2. Does the resource address policies, standards, guidelines, or evaluation criteria related to sustainability in the context of the discipline?	0	1	3	2	1	0	1	0	2	0	1	0	0	3
3. Does the resource suggest a change management approach by addressing the impact of the deploying new sustainable practices/hardware/software (e.g. technology adoption model)?	1	2	1	2	2	3	1	0	0	0	1	1	1	2
Curriculum integration														
1.Does the resource fit into a standard disciplinary curriculum, covering either a focussed or comprehensive curriculum area?	2	3	2	2	3	3	2	2	1	2	3	3	3	1
2. Which areas(s) (Need to map to CC2001/5/8)														3

3.Can the resource easily be adapted to fit into the context of the courses?	1	2	2	1	3	2	2	1	1	2	3	3	3	3
4. Is the resource well written and appropriate to the students' level (e.g. undergraduate, graduate, non-major)?	2	2	2	1	3	1	3	3	3	3	3	3	3	3
5. Does the resource include questions, problems, projects, or case studies to engage the students in thinking about the discipline in the context of sustainability (or vice versa)?	0	1	1	0	3	2	0	0	0	1	2	0	1	3
Linking and Connection														
1. Does the resource provide a clear pathway where the discipline can be linked to social or environmental sustainability (e.g., carbon footprint, ecology enhancement, social equity)?	1	3	3	3	3	3	2	1	0	1	3	1	2	2.5
2.What are the specific areas of sustainability that the resource can be linked to (e.g., CO2, electricity use, energy use, social issues, ecology)? (see table 2)														
3.Can a definite ecological/social impact or consequence be identified, whether positive or negative?	2	3	3	3	3	2	2	1	3	2	2	0	2	3
4.Does the resource encourage students and practitioners to see themselves as directly responsible for sustainability?	1	2	3	1	2	1	1	1	1	1	1	0	0	3
Disciplinary Issues														
1.Does the resource address current practices and challenges related to sustainability in the discipline?	1	2	3	2	3	3	2	0	0	0	2	0	2	1
2.Does the resource address the sustainability impact of typical design choices related to the discipline?	0	3	3	3	3	3	1	0	0	0	0	0	0	1
3.Does the resource indicate specific areas of the curriculum to which sustainability is particularly relevant?	0	3	2	1	3	3	0	0	1	0	2	2	2	1
4.Does the resource provide a conceptual framework for understanding sustainability issues in the context of the discipline?	0	2	2	3	2	0	0	0	0	1	0	0	0	2
5. Does the resource make a clear distinction amongst the different meanings of "sustainability" used in the discipline (e.g., social sustainability, environmental sustainability, sustainability of the software system itself)?	0	2	0	0	0	0	1	0	0	0	0	0	0	3