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A Curriculum on Sustainable Information Communication Technology

Program zrównoważonej teleinformatyki (ICT)

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Abstract

Economies are increasingly becoming dependent on Information Communication Technology (ICT) and concerns over sustainability have called for the investigation of the relation between sustainability and ICT. While the majority of the studies in this field have an environmentalist focus in this regard, technical, economical and societal concerns on sustainability have arisen in the last decade. Today, more and more studies are addressing the need for the inclusion of sustainability as a design goal for ICT development and for the systems that rely on ICT. Therefore, the integration of education on sustainability in the curriculum is imperative for current and future generations of professionals to accomplish this goal. In this paper, we propose a curriculum for sustainable ICT along with the expected learning outcomes and components. The course design is based on a multi-faceted approach that embraces different viewpoints on sustainability and aims to increase students' awareness of the complex nature of sustainability.

Key words: sustainability, Information Communication Technology, ICT, curriculum, professionals

Streszczenie

Świat w coraz większym stopniu zależy od Teleinformatyki (Information Communication Technology, ICT). Warto zadać pytanie o relację pomiędzy zrównoważonym rozwojem a Teleinformatyką. Większość przeprowadzanych badań koncentruje się na aspektach środowiskowych, kwestie techniczne, ekonomiczne i społeczne pozostają w cieniu. Dziś jednak coraz częściej wyrażany jest postulat wskazujący na konieczność uwzględnienia aspektu zrównoważoności w tworzeniu systemów teleinformatycznych i w podsystemach, które są od nich zależne. Dlatego uwzględnienie w programie nauczania problematyki zrównoważoności stanowi imperatyw dla obecnych i przyszłych profesjonalistów.

W tym artykule proponujemy program dla zrównoważonej teleinformatyki, uwzględniający zarys treści programowych i efektów kształcenia. Program oparty jest na wieloaspektowym podejściu, obejmującym różne punkty widzenia, którego celem jest zrozumienie przez studentów złożoności problematyki zrównoważonego rozwoju.

Słowa kluczowe: zrównoważoność, teleinformatyka, ICT, program, profesjonaliści

1. Introduction

The key challenges of the 21st century can mainly be characterized by their global impacts and Greenhouse Gases (GHG) effects. Climate change and sustainable development are only a few instances in this regard. *Sustainable IT* and, especially, *sustainable IT services* are terms that are becoming synonymous with an emerging second wave of green computing innovation (Harmon & Auseklis, 2009). They further argued that sustainable IT strategies are driving sustainability beyond just energy use and product considerations. Environmental issues impact IT business' competitive views in new ways and organizations, with the technology and vision to provide products and services that address environmental issues, will cherish such an edge along with financial and other benefits (Murugesan, 2008). He also suggested that in future green use, disposal, design and manufacturing will be adopted. Harmon and Auseklis (2009) support the view that ecological issues, involving IT product and service design, supply chain optimization, and changes in processes to deal with e-waste, pollution, use of critical resources such as water, toxic materials, and air-shed – will need to be addressed in better detail. ICT infrastructure accounts for roughly 3 percent of global electricity consumption and the same percentage of greenhouse gases (Kumar & Mieritz, 2007). A Gartner study found that data centres, with their associated servers, air-conditioning, fans, pumps, uninterruptible power supply (UPS), and so on, use 100 times the energy per square foot of an office building (Capuccio & Craver, 2007).

Societal value calls upon organizations to build social responsibility and sustainability into their business practices (Savitz, 2012; Senge et al., 2008). According to Jenkin et al. (2011) Green IT and systems refer to initiatives and programs that directly or indirectly address environmental sustainability in organizations. Molla et al. (2009) also maintains that Green IT is emerging as an increasingly important issue, as organizations come under pressure to address environmental sustainability concerns. Green information technology (Green IT) is an emerging discipline and issues related with it are of growing concern for the business and have social and environmental impact (Mishra et al., 2011). Green IT can support, assist, and leverage other environmental initiatives by offering innovative modeling, simulation, and decision support tools such as software for analyzing, modeling, and simulating environmental impact, environmental risk management, platforms for eco-management, emission trading, ethical investing, auditing and reporting energy consumption, environmental knowledge management systems, including geographic information systems and environmental metadata standards, etc. (Murugesan, 2008). Akman & Mishra (2014) explored individuals' environmental behavioral intentions using the theory of planned behavior (TPB).

Business for Social Responsibility, a leading *corporate social responsibility* (CSR) association, defines societal value for businesses in terms of achieving commercial success in a manner that honors ethical values and respects people, communities, and the natural environment (M. E. Porter & Kramer, 2006). According to Donnellan et al. (2011) Sustainable ICT can develop solutions that offer benefits both internally and across the enterprise by:

- aligning all ICT processes and practices with the core principles of sustainability, which are to reduce, reuse, and recycle; and
- finding innovative ways to use ICT in business processes to deliver sustainability benefits across the enterprise and beyond.

There is an increasing interest in teaching sustainability in engineering and in ICT-related educational programs. The growing concerns on the environment call for urgent action to renew programs and courses for sustainability (Desha, 2014; OECD, 2007). On the other hand, the search for sustainability also creates business and *green collar* job opportunities which require a skilled and knowledgeable work force (Deitche, 2010; Runciman, 2012; Worthington, 2012). In a study that investigates what final year engineering students know about sustainable development (Nicolaou & Conlon, 2012), it was shown that despite the inadequate personal commitment and knowledge with regard to sustainable development topics, engineering students recognize sustainable development as an important topic for their profession.

The term *sustainability* is highly dependent on one's adopted perspective, and there is a broad variety of such perspectives on Sustainability in ICT (Hilty & Aebischer, 2015; Penzenstadler & Femmer, 2012). Besides, the broad and complex nature of sustainability requires an understanding and analysis of the dynamic, non-linear, and long-term relations between the elements of a system extending beyond structural, linear and short-term relations (Easterbrook, 2014). Therefore, it is crucial to consider these factors in the approach to curriculum renewal for teaching sustainability (Warren et al., 2014).

Sustainability is becoming a significant emerging area in Information Technology (IT) as contribution of IT to safeguard our future, and as evolving market segment. IT's high productivity in combination with short life-cycles and, on the other hand, growing resource problems of our planet have the point that IT professionals should take their share of responsibility for sustainability. Therefore, there is a need to include the concept of sustainability in university curricula. Furthermore, the challenge is to motivate and interest students and faculty for sustainability, identify spheres of activity for IT professionals, build up competence fields for solutions, and incorporate the topic into the syllabi.

In this paper, a curriculum for sustainable ICT is proposed along with expected course outcomes. The course can be adopted by information technology, information system and inter disciplinary departments/centers. The rest of this paper is organized as follows: Section II provides an approach to course development and up-to-date information about the work carried out in this area. Section III illustrates the proposed curriculum and analysis of this work. Finally, Section IV concludes and highlights some of the future direction for the proposed course.

2. Approach to Sustainability in ICT Curriculum Development

Sustainability is a complex and multi-faceted term. The term has been used to refer to many different concepts and values in various contexts (Hilty & Aebischer, 2015; Pappas et al., 2013). Taking a system thinking approach, which relies on three parameters of system (or resource): function and time horizon, once can define *sustainable use* in a ternary relation as the use of a system S with regard to a function F and a time horizon L, which means using S in a way that does not compromise its ability to fulfill F for a period L (Kaprawi et al., 2008). It is clear that the relativity of such a relation comes from the fact that it depends on how system S, function F, and time horizon L are defined in context (Hilty & Aebischer, 2015). On the other hand, values determine the expected qualities and emergent behavior of a system and its interaction with the surroundings (Dołęga, 2007; Penzenstadler & Femmer, 2012). For instance, the Brundtland Commission defines sustainable development as the *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*, which emphasizes environmental conservation, poverty reduction, gender equity, and wealth redistribution as key values for sustainable development (Ahmed & Shuaib, 2012). Durdik et al. (2012) emphasize on an economic aspect and consider sustainability as the ability for cost-efficient maintenance and evolution of software systems. On the other hand, it can refer to a set of technical practices, principles and goals related to the design and manufacture of products (Software Sustainability Institute, 2015). Therefore, values, that stimulate the desire for sustainability, include various viewpoints of ecological, economic, societal, humanitarian or technical nature or their combinations (Penzenstadler & Femmer, 2012). These value domains are also in line with *five capitals* for sustainable development (Nicolaou & Conlon, 2012). Together, these value domains constitute an important dimension for understanding the relation between ICT and sustainability (Deitche, 2010; Hilty & Aebischer, 2015).

Many conceptual frameworks have been attempted to address ICT systematically in the context of sustainability (Hilty & Lohmann, 2013). Accordingly another core dimension of the relation between ICT and sustainability is the impact dimension of ICT which are given as first, second and third order effects (Cai, 2010; Hilty & Aebischer, 2015; Mann et al., 2010). The first order (or lifecycle) impact refers to the direct influences created by the physical existence and the processes involved including design, production, distribution, operation, maintenance and disposal of ICT systems and their components. The second order (or Enabling) impact refers to actions that are enabled by the application of ICT, such as stimulating consumption of other resources (induction effect), shortening the useful life of another resource (obsolescence effect), replacing the use of another resource (substitution effect), or reducing the use of another resource (optimization effect). The third order (or systemic) impact refers to persistent, long-term and macro-level ICT impacts in the reaction of the dynamic socio-economic systems, such as changes in the culture, economy, corporate structures, or law.

Sustainability is an emergent property of a system; thus, one needs not only to understand the elements of a system, but also the relations and feedback mechanisms within that system. Systems thinking is one of the well-founded approaches to understanding sustainability and is a topic taught in the related courses (Badurdeen et al., 2013; Connell et al., 2012; Martin et al., 2005; T. B. Porter, 2008; Sterling, 2003). It is a framework for seeing interrelationships rather than its elements and seeing patterns of change rather than mere static snapshots (Senge, 1997). Systems thinking approach is particularly useful for ICT related discipline students. Easterbrook (2014) argues that systems thinking provides a domain ontology and a conceptual basis for reasoning about sustainability and transformational change. Additionally, it proposes a set of methods for critical thinking about the social and environmental impacts of technology. The author further argues that the reductionism of computational thinking offers an inadequate approach to dealing with systemic problems including sustainability, inducing blindness to issues such as the social and environmental impacts of ICT. Finally, it is suggested to include systems thinking concepts into the undergraduate curriculum for computer and information sciences.

It has been more than 20 years since the initial calls for integrating sustainability issues into educational curricula were made. The increasing growth of ICT dependent industries and economies drive researchers and practitioners to investigate ICT-Sustainability relationship and transfer the accumulated knowledge to next generation engineers, who play a significant role in the design and use of systems. However, an undergraduate curriculum renewal can be estimated to take 15-20 years to adopt and fully integrate a substantial new set of knowledge and skills (Desha, 2013). Bearing in mind the inclusion of on the job training, it will be some 2-3 decades before students graduating from fully integrated programs will be in decision-making positions using current methods (Desha, 2013). Therefore it is very crucial to develop educational materials and design effective courses in the subject matters.

There are a number of studies that propose methods and models for the renewal of higher education curricula and teaching sustainability in engineering programs (Cai, 2010; Desha, 2013; Heeney & Foster, 2010; Kaprawi et al., 2008; Mann et al., 2010) and report experiences and evaluated changes to curriculum (Ahmed & Shuaib, 2012; Ferrer-Balas et al., 2008; McGarr, 2010). Several others propose teaching sustainability ICT-related engineering programs. Cai (2010) suggested options and strategies for sustainability integration in computing. In the paper, Cai describes a course that includes mainly green computing topics, those that that concentrate on energy efficiency, waste disposal and recycling. Besides, two modules (Server virtualization and Green computing introductory modules) are introduced that can be integrated into other courses. In a recent study, Issa et.al. (2014) discuss the development and delivery of a new graduate seminar course in master's degree in the School of Information Systems dealing with the significance of sustainability and Green IT. The course aims to raise students' awareness of sustainability and Green IT along with sustainability strategies. The course structure comprises paper readings, reporting, presentations and collaborative writing; thus, it is not topic-oriented. Worthington (2012) presents an online green computing course for the Australian Computer Society Computer Professional Education Program. The course topics cover how to assess, and develop strategies to reduce the carbon footprint and materials' use of the ICT operations of an organization. British Computer Society also has a similar foundation course in Green IT as part of a certification program which covers topics that deal with cover carbon footprint and energy efficiency while extending it to include the role of IT in greening other processes and activities within an organization (BSC, 2011).

Our approach to teaching sustainability in ICT programs is based on important and inherent properties of sustainability summarized above. Firstly, it embraces not only the environmentalist perspective, but also technical, economic, humanitarian and societal concerns on sustainability. Second, we follow the systems thinking paradigm and infuse the idea across the proposed curriculum topics. More specifically, a bi-focal analysis of the effects of ICT on sustainability will provide a sound basis for improving sustainability seeing both the forest and the trees. Put in a different way, a good sustainability analysis should be based on the details of the individual and isolated ICT effects within the system and should see this problem system as part of an another system that influences it.

Based on this approach, we propose the following learning outcomes for the curriculum:

- Develop an understanding of broad and complex nature of sustainability (LO1);
- Develop an ability to evaluate and assess the impact of ICT in multiple dimensions in a systemic way (LO2);
- Gain insight into frequently addressed ICT topics in the sustainability literacy (LO3);
- Increase the ability in modeling and analyzing systems for sustainability in complex settings (LO4); and
- Recognize the importance of sustainability in profession and generate commitment at a personal level (LO5).

3. The Proposed Curriculum

Our aim in this study is to provide educators with a sustainability course that investigates its relation to ICT, so that future generations of professionals in various ICT-fields will be able to design and operate systems with due regard for the topics. The following topics are proposed in order to achieve the learning outcomes of this course:

- **Key Concepts in Sustainability (T1)**
  In this topic, students will learn key terms and core concepts in sustainability theory, discourse and practice such as sustainable development, dematerialization, resource-use hierarchy, recycling, etc.
- **Sustainability Value dimensions: societal, technical, economic and ecological values (T2)**
  Here, students will learn about different viewpoints and concerns for sustainability and further seek answers to questions as to which systems (or resources) to sustain and why to do so.
- **Systems Thinking (T3)**
  This topic aims the introduction of the System Thinking paradigm with the additional sub topics to include certain concepts (e.g., emergence, open systems, feedback, cohesion), principles (e.g., separation concerns, abstraction, holism) and patterns (e.g., specialization, generalization, composition, aggregation) to be presented and discussed with a reference to structured educational guides such as *The Guide to the Systems Engineering Body of Knowledge* (BKCASE Editorial Board, 2014)
- **Systems Dynamics Modeling (T4)**
  System dynamics (SD) is a methodology and mathematical modeling technique for framing, understanding, and discussing complex issues and problems (Forrester, 1994). SD utilizes modeling and simulation software to study the behavior of systems over time and enables the application of systems thinking approach to sustainability problems. This topic will complement this approach and provide students with an ability to apply it for sustainability analysis using SD simulation and modeling tools.
- **Green IT (T5)**
  Green IT is a set of principles and practices that aims at environmentally friendly ICT. Under this topic, students will gain insight into the relation between ICT product/service life-cycles and environmental concerns such as energy consumption, waste reduction, and recycling. Here, the role of process improvement will be emphasized since sustainability cannot be achieved by improving energy efficiency and recycling

but also reducing the use of resources. In addition, students will critically evaluate certain technologies such as virtualization in a *green* context.

- **ICT for Sustainability (T6)**
  ICT is an enabler of the studies for sustainability providing tools and techniques for domains of sustainability studies such as Environmental Informatics, Computational Sustainability, and Sustainable Human Computer Interaction. In this lecture, students will learn about a set of selected tools and techniques that are used in sustainability studies such as Environmental Information Systems, Machine Learning and Modeling Tools (Hilty & Aebischer, 2015).
- **Ethics and Sustainability (T7)**
  All sustainability studies are driven by principles which, in turn, require an understanding and questioning human values and practices. Therefore, ethical consideration of sustainability is fundamental, and there is increasing recognition for the importance of ethics component in educational materials (Dahl, 2015). In this respect, a set of principles have been gathered in forms of *Codes of practice* for engineers and published by different institutions (Desha, 2013). In this topic, students will learn about ethical considerations for sustainability such as environmental protection, biological and cultural diversity, distributive justice, peace, security, human rights, and equality.

Table 1 provides a mapping of the contribution of the sustainability topics to the learning outcomes in terms of primary (P) and secondary (S) degrees.

Table 1. Mapping of Topics and Learning Outcomes

	LO1	LO2	LO3	LO4	LO5
T1: Key Concepts in Sustainability	P	S	S	S	S
T2: Sustainability Value Dimensions	S	P			P
T3: Systems Thinking	P	P		P	
T4: Systems Dynamics Modeling		P		P	
T5: Green IT			P		S
T6: ICT for Sustainability		S	P	S	
T7: Ethics and Sustainability			S		P

4. Teaching Techniques

The primary teaching technique used in this course will be collaborative problem-solving. The selection of the collaboration based problem solving pedagogical approach is motivated by the fact that Sustainability in ICT is a relatively new concept and students may not have a clear view about it. Therefore, this approach will increase their abilities in understanding and communicating within a group setting as well as defining the main issues related to sustainability, and proposing solutions. In the interactive lecture sessions students can be engaged in applying the concepts in class assignments, solutions and discussions and also providing feedback to the instructor. In turn, instructor provides an overview of sustainability and its relation to ICT and contemporary issues. Alternatively in such sessions, speakers from faculty and industry can present sustainability problems, solutions to problems and their experience. Field visits can be arranged to ICT organizations which have adopted useful practices to sustain their businesses which have developed an understanding of the elements of ICT and their inter-relations.

There are two main approaches taken to infuse sustainability issues into high-degree ICT programs: centralized and distributed (Cai, 2010; Mann et al., 2010). The proposed course has a centralized design, such that the there is a strong cohesion and dependency between topics. It requires essential knowledge in ICT development and use; thus, it may not be applicable to non-ICT programs as a whole. However, several selected topics can be integrated into other courses in a distributed fashion. For instance, the Green IT topic (T5) can be integrated into IS/ Software Design and Process Improvement courses. Topics T1 and T2 are generic; as such, they can be integrated into engineering courses to achieve LO1. Systems Dynamics Modeling (T4), Systems Thinking (T3) topics are frequently included in engineering program curriculums such as Systems Engineering and Industrial Engineering. The selected topics from the proposed course can be integrated into these curricula so that Systems Thinking and System Dynamics can be applied within sustainability and ICT contexts, thereby creating awareness of the topics in similar programs. In the proposed course, evaluation will be performed based on assignments, case studies, mid-term and final exams in order to assess students' achievement in understanding course outcomes.

5. Conclusions

Sustainability and green IT 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 this area due to its indispensable significance for future. Over the past few years, green computing has received an increasing amount of attention since it is considered as one of the critical factors for protecting the environment (Mishra & Akman, 2014). In this paper, a sustainability curriculum that can be integrated into ICT-related disciplines is proposed. The curriculum aims to support educators and educational institutes to transfer current theory and practice on sustainability to their programs. In the proposal, a balance between theoretical and practical topics is maintained so that students will be aware of current focus of ICT sustainability and can apply their knowledge and skills in various contexts. The systems' complexity is increasing and as more and more systems rely on ICT components, it requires multi-disciplinary knowledge in their design and analysis. Therefore, in the near future, it is expected that studies from any sustainability perspective will require ICT professionals to have skills and knowledge to handle such complexity. Mishra et al. (2014) supported that ICT professionals with positive intentions towards Green IT issues are actually practicing it in their work and Theory of Reasoned Action (TRA) is in favor of GIT adoption in organizations. The adoption of the proposed course will be a first step in this direction. It is also anticipated that the course will stimulate research projects, theses as well as undergraduate research opportunities. Students will take advantage of the course in achieving sustainability goals of industrial projects after graduation. Future offerings of this course will emphasis on problems and techniques regarding ICT sub-domains such as Software Engineering, Information Systems Engineering and Computer Engineering. The organization of the course will evolve into a framework maintaining the current topics as core and extending it with discipline specific topics.

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