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SUSTAINABLE DEVELOPMENT, TECHNOLOGICAL AND INDUSTRIAL IMPACTS ON ENGINEERING EDUCATION

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ABSTRACT

The past industrial revolutions had negative effects on our world especially on environmental and social aspects. Hence, our societies must be able to steer the continued industrial revolution into the direction of sustainability. In particular, the current industrial revolution relies on the technologies of the Internet of Things, which open the ways to the development of sustainable solutions in order to meet the needs of the present without compromising the needs of the future. In the transition towards a sustainable society, teaching sustainability is necessary to ensure sustainable design and preserve the ecosystem. Consequently, educating engineering students on sustainable development is wide spreading and is actually taking place worldwide in many modern faculties and universities. This article examines the teaching methods for a sustainability subject and builds on the experience of others and a wide spectrum of methods in order to provide guidelines for curriculum design. The design is based on innovations in technologies to cover sustainability along with environmental and social implications. The article also provides a criterion for evaluating the impact of executing the proposed sustainable development curriculum.

KEY WORDS

sustainable development, teaching methodology, learning outcomes, ICT, IoT

CLASSIFICATION

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INTRODUCTION

The aim of the new industrial revolution is the ability to be sustained, which is the ability of not depleting natural resources or harming the environment. The developing sustainable products that use energy wisely can support long-term ecological balance and preserves the natural resources for future generations. As such, sustainable development aims to meet human development goals while at the same time sustaining the natural resources. To work toward this gaol, it is a must to strive to utilize sustainable workforce where people are educated to practice the new strategic sustainability goals.

Hence, education for sustainability is becoming extremely important in the strive to reach a sustainable world. The education for sustainability is defined as a transformative learning process that equips students, teachers, and school systems with the new knowledge and ways of thinking needed to achieve economic prosperity and responsible citizenship while restoring the health of the living systems upon which our lives [1]. However, the design and introduction of a new curriculum into an educational system requires the compliance with many factors including the study program that is being followed by the institution, the need and capabilities of the students and governing laws and regulations. Some of these regulations are inflexible and may require many levels of approval. This adds some challenges on the course designer and the way to implement the course. A good method should not only allow flexible design but allows the gradual introduction with wide availability to all the intended users. As such, the approach followed in the design of the curriculum uses compatible models in teaching engineering students. The course can be introduced gradually into the various departments as per a pre-set plan then get expanded into the school curriculum in subsequent semesters.

Education around the world depends more and more on the use of technology and the integration of the new teaching methods. Educational technology is "The study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources" [2]. However, while smart educational environment uses the newest trends of Information Communication Technology (ICT), it can also have negative impacts on the world resources. ICT effects of the production, use, and disposal of products. As an example, the energy consumed for production of hardware affects the environment. ICT also effects of the functions provided during use of the technology. As an example, ICT enables new work models that can change workforce's commuting habits. As such, there is a need to investigate the effect of using ICT equipment on the environment, society, and the sustainable development (SD). Moving forward, the enabling technologies such as Internet of Things (IoT) can be used in many ways to help sustainability.

The environment and society are very much close to sustainable development, after all, it is the environment that need to be improved for the best conditions of the society. As a result, the concepts of sustainable development can be combined with environment and society into one syllabus. Therefore, it is essential to educate the future professionals who will work in the sustainability field. The teaching must be done in a way that it becomes relevant and possible for the students to relate to and this can be achieved by introducing stimulating exercises.

Hence, it is becoming clear that sustainable development requires good attention, in particular, within the fields of engineering. The United Nations (UN) Sustainable Development Goals (SDG) are agreed upon in 2014 [3]. The 17 SDGs cover not only engineering aspects but all other areas that affect the environment and society. It is important to notice the characteristics of sustainability and its relation to the environmental issues; such as climate change, reducing greenhouse gas emissions, and the limited supplies of non-renewable resources.

Furthermore, the ICT community needs to conduct research on how to educate students on topics of sustainable development [4]. The students need to be taught how to get the required answers on their own and then work on applying the obtained knowledge to their future professions. The instructor has to engage the students and make an impact on their thinking [5].

The purpose of this article is to investigate the relatively new area of sustainable development within the field of engineering education. First, the teaching methods in similar published research papers are reviewed with the aim of coming up with an innovative method for introducing the topics to engineering students who have no prior knowledge about the subject area. Next, this article introduces a methods for assessing the effectiveness of the new curriculum mainly through specially designed surveys conducted on the participating students. The following section reviews the related work after which a section is written to introduce the methodology of new curriculum development. A section that covers the evaluation criteria of the curriculum is then introduced followed by the conclusion.

RELATED WORK

In reviewing of relevant systems, the different methods used in teaching sustainable development are explored. One relevant example is the Royal Institute of Technology (KTH). This institute has taken a long trip on teaching sustainability to students. Each student enrols in at least one SD course during his/her degree. A sample of engineering related courses is given in Table 1.

Table 1. A Sample of Related Sustainability Courses. Source: actual course contents prepared by the authors.

AG1815 Sustainable Development, ICT and Innovation
AG1814 Sustainable Development for Computer Science
AG3206 Futures Studies for Sustainability
DM2573 Sustainability and Media Technology
DM2720 Sustainable ICT in Practice
EH1110 Global Impact of Electrical Engineering
EH2221 The Sustainable Electric Power Engineer
EH2220 The Sustainable Electric Power Engineer

The teaching method varies from one course to another; some use direct method while others use indirect method. The first method relies on a fixed SD curriculum with pre-determined related topics given in lectures, and the students are then given assignment or projects related to these topics. The later method uses topic from the specific engineering discipline and ask the students to figure out the effect of a particular problem on sustainability. In both cases, wide spectra of teaching methods and techniques, including student projects and presentations, can be used. Moreover, external seminars by subject matter experts can broaden the students' knowledge areas and experience. It is worth mentioning that the introduction of sustainability via a mixture of the above methods is quite possible with availability of the learning techniques and seminars.

KTH also has a two-year master program in sustainable technology that is based on the concept of Industrial ecology with focus on balancing technical, economic, social, and environmental systems and processes. It is composed of some mandatory courses (like environmental system analysis, industrial ecology, technology and ecosystems, and research methodology) and some elective courses (like trans-disciplinary approaches for system innovations, waste management, ecological economics, environmental modelling and management), and then it ends with a degree project and a thesis [6].

Another good example is the master program in sustainable development at Uppsala University. The program is composed of four semesters and 120 credit hours. It introduces sustainable

development's worldviews and visions towards natural resources, society and environment; energy, water and food. It also ends with a degree project in sustainable development [7].

The United Nations (UN) has been inspirational instrument in developing the concepts of Engineering Education for Sustainable Development (EESD). The UN has named the decade 2005-2014 the UN Decade of Education for Sustainable Development led by the UNESCO [8]. Consequently, there has been substantial achievements made internationally relevant to EESD [9]. Examples of EESD initiatives were documented by academic authors in papers published in either conference proceedings or peer-reviewed scientific journals.

In Europe, at Delft University of Technology, Netherland, Mulder presented sustainability as a tool to open up the windows of engineering education [10]; followed by Kamp who discussed engineering education in sustainable development [11]. In Sweden; Lundqvist and Svanstrom presented inventory of content in basic courses in environment and sustainable development at Chalmers University of Technology [12]. Hanning et al. addressed the issue of educating engineers for sustainability and presented a comparison between obtained competencies and Swedish industry's needs [13]. In United Kingdom; Fenner et al. illustrated embedding sustainable development into curricula of engineering departments at Cambridge University [14]. Humphries-Smith discussed sustainable design and the design curriculum at Bournemouth University [15]. Fletcher et al. presented the teaching of sustainable development at Aston University [16]. Lozano elaborated on diffusion of sustainable development in universities' curricula at Cardiff University [17]. In Spain; Ferrer-Balas et al. discussed education transformation towards sustainable development at the Technical University of Catalonia [18].

In the United States of America; Allenby et al. published a national overview of EESD in the American institutions of higher education [19]. Epstein et al. presented EESD case study at the Massachusetts Institute of Technology [20]. In Japan; Onuki and Takashi elaborated on the graduate program in sustainability science at the University of Tokyo [21]. Uwasu et al. discussed mobilizing science and technology towards sustainability at Osaka University [22]. In China; Xu, K. presented the status of EESD in Chinese universities within a national overview about engineering education and technology in a fast developing China [23].

In Australia; Mitchell discussed concentricity and its consequences upon integrating sustainability in chemical engineering practice and education at University of Sydney [24]. Bryce. et al. implemented a program in sustainability for engineers at Sydney University of Technology [25]. Daniell and Maier illustrated their embedding sustainability in civil and environmental engineering courses at University of Adelaide [26]. Davis and Savage discussed the challenges and opportunities for professional education with EESD perspective at Queensland University of Technology [27]. Goh presented a proposal for reform aiming at curriculum renewal in engineering management education at University of Southern Queensland [28]. Koth and Woodward presented result of auditing a course titled civil engineering for sustainability at the University of South Australia [29]. In New Zeeland; Mann and Smith presented computing education for sustainability at Otago Polytechnic [30].

It is clear from the above references that sustainable engineering education is getting major attention from academic institutions all over the world. In fact, sustainable development enables the role of engineers in all the engineering professions, and as such, this article focuses on introducing sustainability curriclum for institutions that are starting to join the race for a sustainable world.

METHODOLOGY OF CURRICULUM DEVELOPMENT

The design of a new sustainable development curriculum must include a rich set of features that allows it to be used for wide range of educational purposes. The curriculum should not

only introduce the concepts of the sustainability requirements but also covers topics on environment and society such as the greenhouse effect, global warming, and climate changes. A list of the curriculum main topics is given in Table 2. The concepts of sustainable development are first introduced along with the United Nations definitions and future plans. Next, ICT solutions for sustainable development are introduced followed by the concept of smart sustainable cities and their environment.

The United Nations Brundtland Report, issued in 1987 [31], states that Sustainable development is development that meets the needs of the present without compromising the needs of future. While the general meaning of this definition can be understood, it is not specific to be used for implementing sustainability. As such it took several rounds until the UN came up with agreed upon sustainable development goals in 2014. On 25 Septenber 2015, the UN General Assembly adopted the 2030 Agenda for Sustainable Development and each country started its planning to take action in accordance with its respective capabilities.

Table 2. The Overall Course Topics. Source: actual course contents prepared by the authors.

Introduction to Environment and Sustainability
Humans and the Environment
Gases Contributing to the Greenhouse Effect
Global Warming and Climate Change
Concept of Sustainable Development and UN plans
Introducing ICT-Solutions for Sustainable Development
Concept of Smart Sustainable Cities and the Environment
Air Pollution and the Environment Air Quality Index
Water Resources and Ground Water
Water Pollution and Wastewater Treatment and Disposal
Solid Pollution and Solid Waste Management
Control and Disposal of Wastes, Mitigation, Reuse/Recycle
Industry Growth and Alternative/Green Energies

Engineering students in particular should be taught how to perform sustainable design, which is a collaborative approach to fulfil sustainable development strategies and goals. The design strategies include things such as energy conservation and elimination of toxic materials. Sustainable architecture education for engineers should focus on using the knowledge and skills in sustainable design in order to achieve energy efficiency as well as convenience in the built environment [32]. The main objective is to meet the main pillars of sustainability; economic (growth, capital, etc.), social (human resources, health, education, etc.), and environmental (habitat, species, biodiversity, etc.).

While ICT has positive effects on the society, it also has negative effects. The positive effects include increased access to information, increased opportunities for education, and improved telecommunications. The negative impact of ICT on society includes reduced personal social interaction in daily lives and also causing some ethical problems due to the amount of misleading information available on the internet. Sustainable development requires a deep societal transformation in many areas and ICT is already affecting the society. Hence, there is a need to steer the digital revolution into the direction of sustainability. The current cyber-physical revolution is in a position to give a big boost to sustainability.

It must be mentioned that ICT has adverse effects on sustainability as well. The most apparent effect is due to the life cycle of ICT equipment themselves. For instance, the production of ICT hardware consumes a vast amount of energy, not to mention the energy consumed during the operation of ICT hardware and the data centres. Another important negative factor is due to the mining of scarce metals raw materials for ICT hardware which causes depletion of natural resources as well as the social and environmental impacts of

mining. Then, comes the pollution caused by informal recycling and final disposal of ICT hardware. In order to mitigate the ICT related issues, the effect of hardware production needs to be reduced via things such as optimizing materials used for building the hardware, designing hardware and software that are aware of energy consumption, and build software that runs on multiple versions of hardware without a need for upgrade.

As mentioned before, the IoT enabling technologies can be used in many ways to help sustainability. IoT can support the monitoring of sustainable development impacts by providing ways to assess the carbon footprint, assess the scrap recycling, and assess the agriculture irrigation, just to name a few. As such, the proposed curriculum is based on introducing the IoT technology to the targeted students as it can be utilized in all the engineering disciples. The students are also provided with examples from different engineering areas to broaden their understanding of the use of the new technology.

The IoT itself is a global infrastructure where devices, machines and sensors can connect and exchange information over the Internet. It relies on using wide variety of sensors such as temperature sensors, pulse sensors, location sensors, accelerometers, and even microphones and cameras. There are many research groups and consortiums [33] that focus on IoT development and there are abundant of IoT applications in all areas including education, transportation, and manufacturing, leading the way to smart cities.

Meeting sustainability goals in cities requires sustainable use of resources which requires the evolution of cities into smart cities or a smarter cities with many smart applications. Internet of Things technology is the critical enabler of smart city development and also of meeting the sustainability requirements such as energy efficiency, improved security, and other convenient applications. It is known that cities consume about 75 % of the globally produced energy [34]. Technological advances must make cities becoming more intelligently connected in order to save energy and operating costs. IoT enables energy technologies to be more efficient and sustainable by supporting new ideas such as virtual power stations and energy storage technology having the potential for energy savings [35].

Thus, the implementation of the curriculum utilizes various techniques in order to provide the maximum benefits to the students. In addition to the lectures on the topics listed in Table 2, the students are exposed to another weekly session where they present their acquired knowledge. At the beginning of the course, a list of possible topics are given to the students to select the ones that interest them. The students can also select a relevant topic outside the list if they wish to do so.

The course itself is composed of four contact hours per week; two hours for lecturing on the identified topics using two way interactive communication with the students. The other two hours are used for various objectives, the first of which is to involve the students in researching topic related to sustainable development. Teams of two-students each are formed and are asked to collect information on one of pre-selected topics then present it in the class with all other students attending. Second, inviting guest speaker on relevant topics provides the students with empirical explanations and open discussions. In addition to these activities, site visits to related organizations are arranged for the same concept.

After completing the lectures on sustainable development, the students were asked to participate in a survey in order to assess their understanding of the sustainability issues and the way the information was disseminated to the class. The results of this experiment can be used to further improve the course contents and teaching methods in order to produce better learning outcomes.

EVALUATION CRITERIA OF THE CURRICULUM

To evaluate the impact of the sustainability development education on students' knowledge, there must be a way to assess the learning outcomes of the curriculum on the students. This

can be done through a formal survey about the sustainability course under consideration. The survey has to be conducted on a proper sample of the students so as the results of the course statistics can be properly documented. The structure of the proposed survey measures the sustainable development course topic acceptability, the teaching methods, the acquired knowledge, and the sustainable development applicability as assessed by the student sample.

First, regarding the teaching methods, when a high percentage of the students (more than 85 %) are satisfied with the teaching methods used in the sustainability course, the intended impact of the course on the students can be easily achieved. From our experience, a high percentage can be obtained through several factors, among which is the interactive class lectures, the posting of the class materials on the web, and the quality of the materials and animation that help the students study the sustainability course. When the students find the sustainable development lecture notes clear and easy to read and study, it will increase their interest in the abstract ideas included in teaching the sustainability concepts. In addition, the students can be extremely satisfied if the instruction dissemination is done through social media which can aid them in communicating their ideas about sustainable development outside classroom formalities.

Moreover, the course should utilize a weekly tutorial section that is very beneficial to getting better knowledge out of the course. The tutorial can organize student teams to work on a prominent topic in sustainable development and present the results to the rest of the class. The student presentations help in enriching the knowledge about related diverse topics as the students are requested to find the relevant literature on the internet related to sustainable development. The tutorial can also include external seminars by guest speakers to help widen the scope of knowledge about sustainable development. A partial sample of the survey form is shown in Table 3.

Table 3. Sample Survey Items. Source: part of actual course survey prepared by the authors.

No.	Item
1	Introducing sustainable development course is essential for engineering students
2	Studying sustainability helps in understanding the social and environmental issues
3	Taking this course broaden my thinking about engineering effects on sustainabilty
4	Sustainability knowledge will help in getting better job opportunities
5	Taking this course opened my eyes to the importance of sustainable development
6	Sustainability skills and environmental awareness is a priority in many corporations
7	A course covering sustainability should be taught in every engineering department
8	Studying sustainability helps in persuing advanced post graduate studies
9	Studying sustainability helps change the behaviour towards the environment
10	I believe engineers are mostly responsible for solving the negative environmental effects due to extensive and diverse industrialization

The survey should give the students a way to express their views about the possible course improvements. A percentage of more than 75 % in this regards is a good indication about the students' involvement in the course materials. For example, some of the students may suggest course improvement or projects related to sustainable development and the environment. This type of suggestions can be easily incorporated in the next offering of the course. From our experience, this course could be more beneficial by arranging field trips to professional environmental organizations and consulting firms.

Topic acceptability within the engineering curriculum via the introduction of a new sustainable development course must be sold to the students. A percentage of 65 % or more on the related survey questions indicates good level of the students' acceptability. The percentage indicates that studying sustainability help the students in understanding the social

and environmental issues and broaden their thinking about the overall engineering effects on sustainable development. Basically, taking this course opens the students' eyes to the importance of sustainable development.

The same results can indicate that a course covering the concept of sustainable development should be taught in every engineering department as engineers are mostly responsible for solving the negative environmental effects due to extensive and diverse industrialization and the studying of sustainability help in changing the behaviour towards the environment.

Another indicator is percent of students who believe that sustainability knowledge will help in getting better job opportunities. The answer to this type of questions can vary from college to another and from country to country as the sustainability skills and environmental awareness are still not a high priority in many corporations. It is important to note that the sustainability development goals are only approved in 2014 and as such the awareness about the topic is not very high worldwide.

On the acquired knowledge area, the overall results should reveal that more than 80 % of the students became aware of the sustainability issues including natural system functions, ecological diversity, and balancing the use of renewable energy sources. This percentage reflects the students' believe that sustainability protect the natural environment while influencing the way we live and that the economic development is giving people what they want without compromising the quality of life.

Moreover, it is interesting to find out if the students understand that the SDGs should not be assessed individually for their feasibility and suitability, without considering the remaining goals and that these goals are inter-related. For instance, reducing inequality within and among cities is one of the sustainability goals that is touching all aspects of human life. Sustainability draws on politics, economics, philosophy and other social sciences. As such, sustainable development focuses on balancing the fine line between the ever increasing human needs and the need to protect the environment.

Finally, relating to SD applicability in different disciplines and the new enabling technologies, it is expected that a small percentage of students be aware of the extended applications. The majority of the students can understand the ICT effects and how they make daily live more productive, and that the future of IoT applications will enhance smart living and build new sustainable smart cities.

CONCLUSION

The innovations in technology and the recent cyber-physical industrial revolution have opened the way for exploring the area of learning, teaching, and curriculum development. The proper teaching of sustainability should be an approach that uses both dedicated specific courses and relevant activities that are integrated into the rest of the teaching curriculum. The importance of this topics comes from the limited resources that must be sustainable in order to balance the quality of life for generations to come [36]. Teaching young generations about sustainable world is of major importance as these generations will have to perform the recommendations of the research studies in this area. Economic, social, environmental, and even cultural concerns must be well understood by the students.

This article addresses the importance to teaching the sustainable development topics into engineering profession and assess its impact. The proposed curriculum is built upon innovations in technologies to cover sustainability along with environmental and social implications. Based on the proposed sustainable development curriculum, a criteria for evaluating the course teaching experience is introduced. Applying the resulting criteria produces great potential in steering engineers in the direction of sustainable design.

It is important to note that teaching for sustainability must rely not only on instruction but also on participation and collaboration. As such, it is instrumental to add tutorial sessions to the course to help in widening the scope of the students. Working in small groups to research a particular related topic and present it to the whole class allows the students to interact among themselves and with the course instructors. Also, using external subject matter experts and visiting actual sites with activities relevant to course topics are effective in motivating the interest of students in learning sustainable development as a new paradigm and finding related applications in the respective engineering disciplines.

Given the limitation on the number of newly introduced curriculum changes that can go into an already accredited engineering study program, the article showed the possible way to tackle the sustainability topics. Based on the importance of this topic for engineers and the effect it has on societal and industrial transformations, the futurestic plan is to introduce a chapter on sustainability in several related courses to be selected from the current study program.

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