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Incorporating the module Engineering for Sustainable Development in the First Year Engineering Program

Dr. Jorge R Lara, Texas A&M University

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Dr. Lara is Instructional Associate Professor of Engineering at Texas A&M University in the First Year Engineering Program. He is faculty affiliate of the Institute of Engineering Education and Innovation and the Energy Institute of the College of Engineering. Dr. Lara received his PhD in Interdisciplinary Engineering in 2005 and his M.S. in Mechanical Engineering in 2003 from Texas A&M University. He held a Post- doctoral fellowship in the Chemical Engineering Department in Texas A&M University. He has served as the Energy Program Manager of the Texas A&M University System, which is composed of 20 campuses across the state of Texas. Dr. Lara serves as journal article reviewer for The International Journal of Heat and Mass Transfer (Elsevier), Desalination (Elsevier), Desalination and Water Treatment (Elsevier), and The Canadian Journal of Chemical Engineering (John Wiley). His research interests are engineering education in sustainable development, sustainable design of complex energy systems, vapor compression desalination, reclaiming produced water in oil fields, modeling simulation and optimization of energy systems, energy and water supply chain, energy use, conservation and lighting technologies for buildings, communications for energy systems, water use in hydraulic fracturing, environmental impacts of energy production, turbomachinery for energy use and its reliability.

Dr. Mark Weichold, Texas A&M University

Dr. Weichold is Interim Executive Vice President and Provost of Texas A&M University, Regents Professor of Electrical and Computer Engineering and Executive Director of the Halliburton Engineering Global Program of the College of Engineering. He received his PhD in Electrical Engineering from Texas A&M University. He has served as Associate Dean for Academic Affairs, TAMU, College of Engineering, 2016 – 2017, Dean/CEO Texas A&M University at Qatar, 2007-2015, TAMU Dean of Undergraduate Programs and Associate Provost for Academic Services, 2003-06, Associate Provost for Undergraduate Programs and Academic Services, 1998-2003, TAMU Associate Department Head and Graduate Coordinator, TAMU, 1996-97. TAMU Associate Director of CEMDAS, 1997-98, TAMU Director of the Program for Automation in Manufacturing, 1991-94, TAMU Associate Director of NanoFab, 1987-90, Dr. Weichold is currently Professor of Electrical and Computer Engineering, his research interest is in Engineering Education in Sustainable Development, Automation in Manufacturing, Nano Fabrication. He has revised freshman engineering curriculum to integrate topics in physics, mathematics, and engineering, serve as a Program Evaluator for Electrical Engineering, and similarly titled programs, for ABET, He is a member of the Board of Governors of Habib University and Chair of its Academic Committee.

In January 2007, he became Dean and CEO of Texas A&M University's branch campus in Doha, Qatar. After completing nine years as the Dean and CEO of Texas A&M at Qatar, he returned to College Station to assume the role of Senior Associate Dean in the College of Engineering.

He is a Life Fellow of the IEEE, a member of the American Physical Society, an ABET program evaluator, and a licensed professional engineer in the State of Texas. In 2013, he was awarded the Abdullah bin Hamad Al Attiyah International Energy Award for 'Lifetime Achievement for the Advancement of Education'.

Dr. Sunay Palsole, Texas A&M University

Dr. Sunay Palsole. is Assistant Vice Chancellor for Engineering Remote Education. He is the founder of the Engineering Studio for Advanced Instruction & Learning, an organization designed to help with supporting technology enhanced innovation within engineering education. A geophysicist by academic training, he has been involved in teaching, technological development and management for more than twenty years. He has published and presented in the areas of online and blended learning, sustainable models of development and data driven decision making. He is the co-developer of the Active Learning in

Engineering Program, which has helped to support faculty in adapting/adopting transformative teaching pedagogies in their teaching.

Prof. Patrick Linke

Professor Patrick Linke is Executive Director, Office of Graduate Studies, Texas A&M University at Qatar (TAMUQ), Doha, Qatar. 2015 – Program Chair, Chemical Engineering Program, Texas A&M University at Qatar (TAMUQ), Doha, Qatar. 2014 – Professor of Chemical Engineering, Texas A&M University at Qatar (TAMUQ), Doha, Qatar. 2011 – Founder and Co-Director, Qatar Sustainable Water & Energy Utilization Initiative (QWE), Texas A&M University at Qatar, Doha, Qatar. 2009 – Chief Engineer and Director of Water and Energy Sectors, Qatar National Food Security Programme (QNFSP), Office of the Heir Apparent, Doha, Qatar. 2008 – 2014.Associate Professor of Chemical Engineering, Texas A&M University at Qatar (TAMUQ), Doha, Qatar. 2007 – Senior Lecturer (UK equivalent to Associate Professor rank) in Process Systems Optimization, School of Engineering, University of Surrey, U.K. 2005 – 2007. Lecturer (UK equivalent to Assistant Professor rank) in Process Systems Optimization, School of Engineering, University of Surrey, U.K. 2001 – 2005. Research Assistant, Centre for Process Integration, University of Manchester (UMIST), U.K. 1997 – 2001.

Incorporating the module Engineering for Sustainable Development (ESD) in the First Year Engineering Program

Abstract

In this paper, the authors present the process followed for the design, preparations, and a suggested implementation and assessment of the module "Engineering for sustainable development" (ESD), which was developed for a first year engineering course at a large University in the Southwest. Conventionally, first year engineering (FYE) program curricula focuses in preparing students for the more advanced engineering courses, and introduces them to a broad engineering practice building up student competencies**.** The FYE program module Engineering for Sustainable Development (ESD) is aimed to address the societal demands for a more sustainable engineering practice by introducing and integrating these principles into the early years of the engineering curricula. It involves introducing the learners to sustainable circular designs as core promoters of a circular economy. A five-semester fold assessment administered to incoming freshman students showed that they know very little to nothing about the fundaments of sustainable development. The students were introduced to the principles of sustainable development in this module, and a post module assessment was administered to gauge student learning. The pre and post module assessments were analyzed to develop the learning objectives based on the questionnaire results. The paper concludes with an assessment of the effectiveness and student engagement. This innovative design thinking will create a new mentality in FYE engineering students.

Introduction

With the prerogative that the world is becoming unsustainable because of the technology in use. Engineering education in sustainable development is a topic being into context for the last few decades. Because of this interest, now, the most representative engineering associations in the world [1], [2], [3].[4], concur to the suggestion that engineering education for sustainable development needs to be incorporated into the general engineering curricula since the early years [5]. Since it is estimated that takes about 20 years before an engineering course is fully incorporated in the engineering curricula [6], it is becoming imperative to initiate as soon as possible the process of creating sustainable development awareness inspiring new mentalities in the new generations of engineering graduates. Economies in the world are moving towards circularity. This process will demand for effective circular engineering designs in support of the increasing societal expectations for more sustainable technology developments. Therefore, engineering education should adjust towards the societal demands and equip engineering graduates with the skills that enable them for a more sustainable practice [3].

Methodology

In order to assess student knowledge and interest in sustainable development with an engineering optic, the authors have developed a knowledge instrument to measure in incoming first year engineering students, their literacy in sustainable development. The questionnaire represents fundaments, from the authors' point of view, what is minimally required to further advance to complex sustainable engineering applications [7], [8], [9]. The objective of the assessment is to

identify in a comprehensive fashion the specifics of lack of knowledge in students in a way that the learning objectives of the module are defined. The following table depicts details of the questionnaire.

Give the formal definition of sustainable development.	Explain how the three integral dimensions of sustainable development can operate in balance.	Define the Net Present Value of and engineering project.
Where and when the topic of sustainable development began being into context?	Why engineering for sustainable development is a multidisciplinary area.	Explain how the engineer in charge of an urban development project can incorporate in the project design process severe weather disaster prevention measures.
Why are engineering educators observing significant shifts in societal expectations of engineering?	Give a formal definition of Design thinking. What are the five (5) steps of design thinking?	Define the life cycle of and engineering product.
Name the three fundamental dimensions of sustainable development.	What is the 6^{th} factor in the sustainable analysis of design thinking?	Define sustainable return on investment (S-ROI) for an engineering project.
Why systems thinking is a powerful tool to incorporate multidisciplinary analysis with complex interactions?	Explain how sustainable development can be embedded into design thinking.	Define Circular economy

Table 1. Details of the 16 questions assessed to freshman incoming students during a five-semester fold time period

Developing and teaching the module

The module was developed following the ADDIE model [10] with the analysis phases driving content and interaction development that was used in class. Analysis of the subject area was carried out before creating a list of topics that were useful for providing reasonable coverage of the subject. Given that, this was a module (two classes period), key elements of sustainable development were identified to develop the module content [11], [12], [13], [14]. At the beginning of the first lecture, a 5 minutes reading assessment test (RAT) is followed by an interactive power point explanation of concepts. To ensure student engagement, the module concluded with in-class-activity in which a real life student-interest-oriented problem was analyzed and solved. Following the delivery of the module, a post assessment was administered to assess student learning, and to gauge student interest in the field.

Assessing student knowledge and interest.

In a five-semester fold time period, the authors performed a study to a total of 816 first year engineering students in a large university of the Southwest (IRB ID: IRB2018-1594). In the study, after a pre-lecture assessment was given, it was consistently found that incoming engineering students completely lack of literacy about sustainable development. Then, a post lecture assessment made quite remarkable however, the student interest in the topic noted by personal interactions followed after the questionnaire.

Based on the outcomes of the questionnaire, the authors tailored a detailed short lecture that was taught and the same questionnaire given to the group of students under the evaluation [15]. Students showed acceptable levels of retention of the material and developed awareness and increasing interest. Figures 1, 2, 3 and 4 depict the notorious difference between the pre lecture and the post lecture assessments.

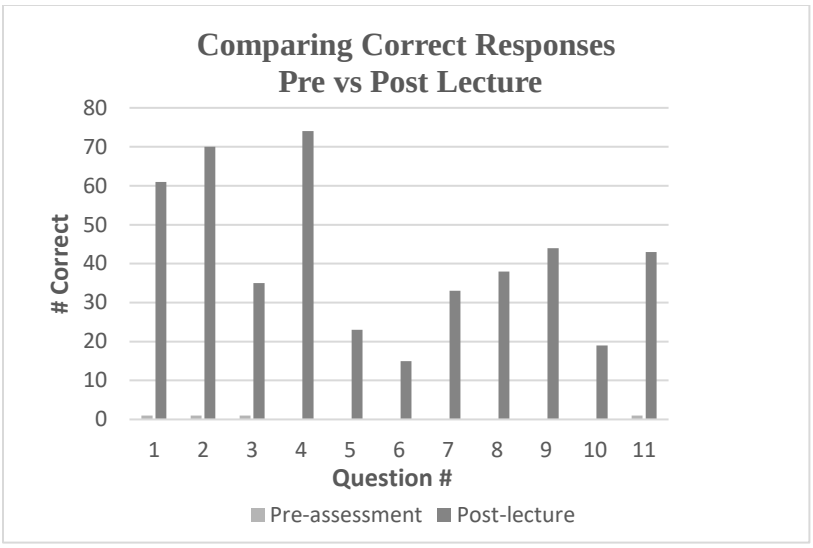

Figure 1. Assessment questionnaire given to 384 first year engineering students of ENGR 112 on spring semester of 2018 (IRB ID: IRB2018-1594). Lighter bars show correct responses before training (Pre-assessment). Darker bars show correct responses after the 2 hours training. The number of responses is averaged to a class of 96 students.

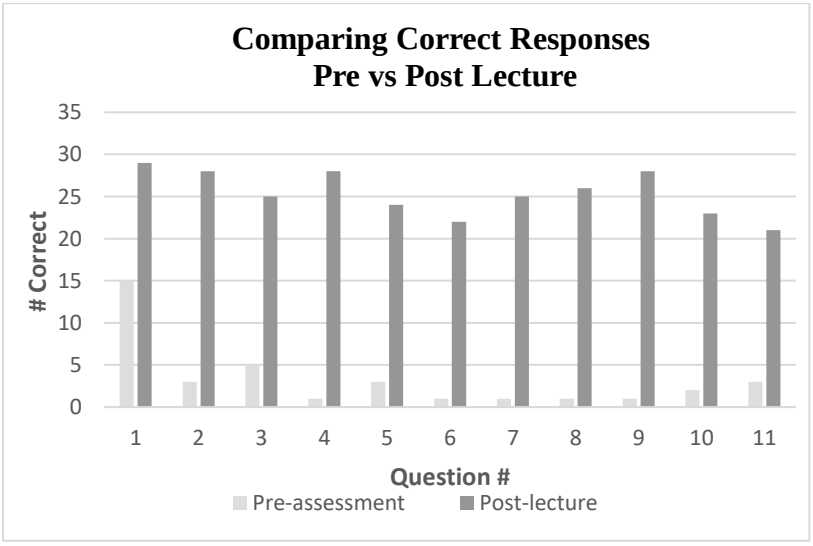

Figure 2. Assessment questionnaire given to 36 first year engineering students of ENGR 112 on summer semester of 2018 (IRB ID: IRB2018-1594). Lighter bars show correct responses before training (Pre-assessment). Darker bars show correct responses after the 2 hours training.

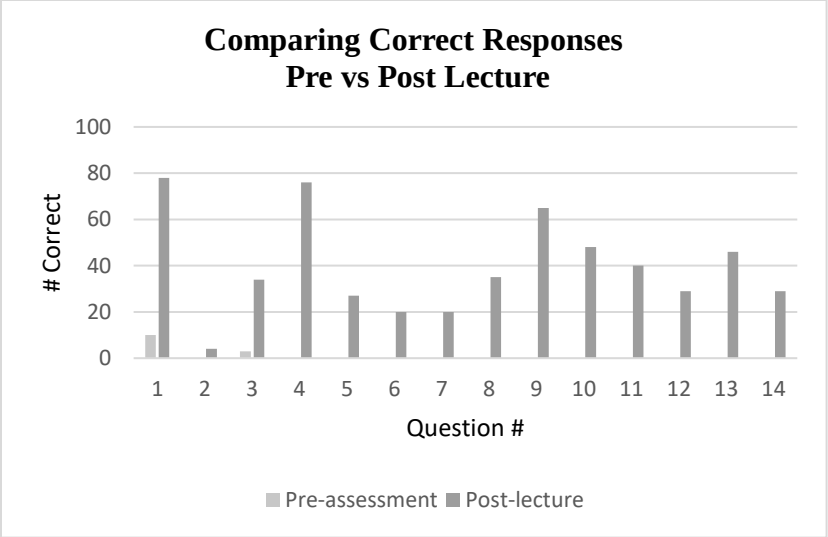

Figure 3. Assessment questionnaire given to 362 first year engineering students of ENGR 112 on fall semester of 2018 (IRB ID: IRB2018-1594). Lighter bars show correct responses before training (Pre-assessment). Darker bars show correct responses after the 2 hours training. The number of responses is averaged to a class of 92 students.

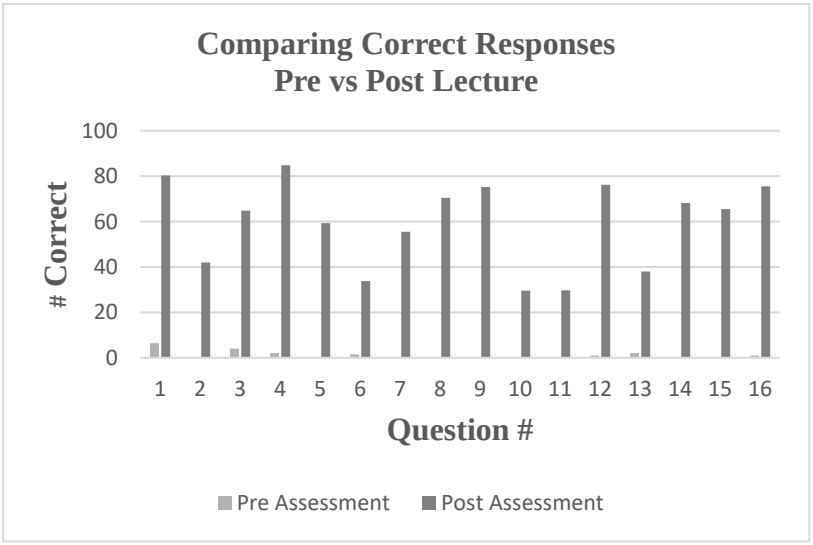

Figure 4. Assessment questionnaire given to 285 first year engineering students of ENGR 102 on fall semester of 2019 (IRB ID: IRB2018-1594). Lighter bars show correct responses before training (Pre-assessment). Darker bars show correct responses after the 2 hours training. The number of responses is averaged to a class of 95 students

Discussion

In this work, students consistently showed a lack of knowledge on the sustainable development principles chosen to measure students literacy in the four assessments performed as depicted in

Figures 1, 2, 3 and 4. Figures 3 and 4 depict 14 and 16 questions respectively after three and five more questions were added to the original questionnaire. Table 1 provides details of all 16 questions assessed. The pre-lecture-assessment provided enough information for a carefully elaborated 2-hours lecture covering the critical concepts of sustainable development with a simple easy to understand terminology for freshman engineering students. The post-lecture-assessment delivered encouraging outcomes because it shows the effectiveness of the preparation of the module. Factually, The National Academy of Engineering formulated in 2004 its vision of the engineer of 2020 [3]. This report outlines a number of aspirational goals where it sees the engineering profession taking a more central normative role in society, including facilitating engineering design *"trough a solid grounding in the humanities, social sciences, and economics".* Rapidly embracing new fields of endeavor, *"including those that require openness to interdisciplinary efforts with non-engineering disciplines such as science and social science and business"*. In addition, taking a lead in the public domain by seeking to influence public policy positively. Critically, the report calls for *engineers to be informed leaders in sustainable development*. Moreover, it notes that this influence *"should begin in our educational institutions, and be founded in the basic tenets of the engineering profession and its actions".* Importantly, The NAE, 2004 report suggests that engineering curricula be reconstituted *"to prepare today's engineers for the careers of the future, with due recognition of the rapid pace of change in the world and its intrinsic lack of predictability"*. Although this recommendation has been in place since 2005, graduate engineers of 2020 are far from being informed leaders in sustainable development. Therefore; considering the identification of this need by the national academies; as well as the prerogative that the world is becoming unsustainable because of the technology in use; and considering that economies in the world are moving towards circularity; and the lack of sustainable development knowledge in students but the subsequent interest they showed when introduced to the subject. The authors propose to incorporate Engineering for Sustainable Development (ESD) in the First Year Engineering program as early as possible as the process of creating sustainable development awareness and inspiring new mentalities in the new generations of engineering graduates.

Future Work

Given the level of student interest and the future need identified in professional organizations, particularly The National Academy of Engineering (NAE), we developed a full course focused on sustainable development. The course learning objectives were defined by using our previous analysis and data from teaching of the single module in the course.

The developed initial learning objectives for the introduction to sustainable development in engineering practice are as follow:

- Explain the definition of Sustainable Development
- Discuss the most important milestones of the History of Sustainable Development
- Identify People, Profit and Planet as the three fundamental dimensions of Sustainable Development
- Discuss the relation of society and the 6^{th} factor (sustainability) in the Engineering Design process

- Recognize the concepts of Profit—Engineering economics
- Recognize the concepts of Planet—Environmental Engineering
- Identify that Society (people), Economics (profit) and Environment (planet) most work balanced in harmony
- Discuss Systems thinking for the interdisciplinary approach of Sustainable Development
- Identify the holistic approach of Sustainable development.
- Explain the concept of Net Present Value for an engineering project
- Explain the concept of sustainable rate of return for an engineering project
- Recognize the importance of Climate Change consequences in new urban developments
- Discuss the concepts of Life Cycle of an engineering design and Life cycle assessment techniques
- Explain the concepts of Circular Economy

Work is underway to collaborate with the first year program directors to integrate the module as part of the first year freshmen course and the creation of a full semester length course for undergraduate engineering students focused on sustainable development and the circular engineering designs for circular economy.

Conclusions

A process to design, implement and measure a module of Engineering for Sustainable Development (ESD) for first year engineering students was detailed. The authors involved introducing the learners to sustainable circular designs as core promoters of a circular economy. This paper shows that a well-structured module with novel concepts of sustainable development for engineers can be taught effectively. The methodology to measure the contents of the module, assures student engagement and promotes student competencies. Incorporating sustainable development in first year engineering programs will inspire students for a new mentality in more advanced engineering courses.

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