2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33340

Work in Progress: Engineering for Sustainable Development: An Undergraduate Course Inspiring New Mentalities in Engineering Students of All Majors

Dr. Jorge R. Lara, Texas A&M University

Dr. Jorge R. Lara, Texas A&M University

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, 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. Sunay Palsole, Texas A&M University

Dr. Palsole is Assistant Vice Chancellor for Remote Engineering Education at Texas A&M University, and has been involved in academic technology for over 20 years. Prior to Texas A&M, he was the Associate Vice Provost for Digital Learning at UT San Antonio, where he lead teams focused on enhancing the learner and teaching experiences across all spaces. His focus on the user experience and data, has led to development and adoption of design strategies that measure learning and teaching efficacies across his service in various institutions of higher education.

A geophysicist by academic training, he began to design multimedia applications for teaching and learning in the late 1990's, developing his first online course in 1996. Since then, he has helped a few hundred faculty from varied disciplines develop hybrid and online courses. He has also taught traditional, hybrid and online courses ranging in size from 28 to 250. He is also co-developer of a Digital Academy which was a finalist for the Innovation Award by the Professional and Organizational Development Network and an Innovation Award winner. He was recently named as the Center for Digital Education's Top 30 Technologists, Transformers and Trailblazers for 2016.

Dr. Mark H. Weichold, Texas A&M University

Dr. Mark H. Weichold, Regents Professor and Halliburton Engineering Global Programs Professor, is an electrical engineer and has worked for General Dynamics Ft. Worth Division, Motorola in Austin, TX and the U.S. Army Electronic Technology and Devices Laboratory in Ft. Monmouth, NJ. He joined the Electrical Engineering faculty at Texas A&M University in 1982 and now holds the rank of Professor.

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'.

Prof. Patrick Linke, Texas A&M University at Qatar

Dr. Patrick Linke is a Professor of Chemical Engineering and the Chair of the Chemical Engineering Program at Texas A&M University at Qatar. Dr. Linke also serves as the Executive Director of the Office of Graduate Studies. He is the holder of the Qatar Shell Professorship for Energy and Environment.

Work in Progress: Engineering for sustainable development. An undergraduate course inspiring new mentality in engineering students of all majors.

Jorge R Lara, Sunay Palsole, Mark Weichold, Patrick Linke
Texas A&M University,
jlara@tamu.edu, sunay.palasole@tamu.edum-weichold@tamu.edu,
Patrick.linke@qatar.tamu.edu

Abstract

There is a realization that the world is becoming unsustainable because of the technology developed by engineers. National and international engineering bodies have recognized this problem and have articulated the need for sustainable engineering. This is creating an increasing social demand both nationally and globally to graduate engineers who have been trained to respond to the modern economic and environmental challenges. In a previous work at a large university in the Southwest, the authors developed an instrument to measure sustainable development literacy in incoming freshman engineering students. This work demonstrated a lack of understanding about sustainable engineering among the incoming freshman and led to the development of a module on sustainable engineering. The student engagement and interest in this module was measured, and these results have led to the design of a full semester long course titled Engineering for Sustainable Development for undergraduate students of all majors. The course took a modular approach in its development with each topical module having clearly defined and measurable outcomes with some independence. Responding to those demands for a more sustainable engineering practice, the course involves sustainable circular designs as core promoters of a circular economy. This innovative design thinking will create a new mentality in engineering students. In this paper, the authors present the process followed for the design, implementation and assessment of the course "Engineering for sustainable development" aimed to introduce and integrate sustainability engineering learning early in the engineering curriculum.

Introduction

The World Commission on Environment and Development (WCED) in 1987, defined sustainable development as *"The technology development that meets the needs of the present for people without compromising the ability of future generations to meet their own technological needs"*. Since the United Nations Conference Declaration in the Human Environment in 1972, and the subsequent Declaration of Rio de Janeiro in 1992, the topic of education in sustainable development has been brought into context. Furthermore, The United Nations Educational Scientific and Cultural Organization (UNESCO), called for a Decade of Education for sustainable development from 2005 to 2015 [1]. This worldwide reflection is creating a new engineering education culture. Engineering educators are observing significant shifts in societal expectations of the engineering profession to help address immediate and longer-term sustainable development challenges. According to the World Federation of Engineering Organizations (WFEO), engineering plays a significant role in planning and building projects that preserve natural resources, are cost-efficient, and support human and natural environments [2]. 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 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"* and 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 and notes that this *"should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions".* 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."*

Engineering education in sustainable development (EESD) should allow every human being to acquire the knowledge, skills, attitudes, and values to shape a sustainable future [4]. While campus sustainability efforts have been made at colleges and universities across the United States of America, education in sustainable development has yet to be codified into standards for most engineering disciplines [5]. At many campuses, engineering students can graduate without an understanding of core sustainability concepts, critical issues, or the change management and systems-thinking skills necessary to participate in innovative sustainable engineering solutions.

Therefore, higher education institutions are being called upon to help or lead the sustainability transformation to train the global citizens and leaders of the future [6]. Engineering graduates skilled on multidisciplinary disciplines across formal engineering education will be able to address the goals from health and energy to climate change and biodiversity [7].

A small number of universities in the United States have selectively implemented sustainable development thinking in their formal curricula. However, engineering graduates in the coming generations will need a more standardized instruction focused on sustainability to allow them approach holistically problems of society, economy, and environment and graduate with the foundation and technical skills supported by systems thinking, multidisciplinary training, and practical engineering application to confront the challenges found in modern engineering practice [8].

Based on data from our previous work with on measuring literacy in sustainable engineering and the development and results of one teaching module, we proposed the creation of a course at the undergraduate level designed to help students develop sustainable thinking in engineering [9]. The key feature of introducing this course early in the curriculum is to ensure that the students are trained in integration sustainability in their thinking which will help integrate sustainable engineering into whichever discipline they choose. The outcomes of this research will help associate academic needs for faculty training in a way that allows instructors to be prepared to present lecture materials for fundamentals in sustainable development.

Contributory work at large Southwestern University

<u>The measuring literacy instrument.</u> None of the Sustainable Development Assessment methodologies developed so far in the United States assesses specific literacy in first year engineering students. Previous studies performed assessed general sustainability concepts rather than a more focused assessment relevant to understanding sustainable development from an engineering point of view, with interest in holistic systems thinking and a design thinking approach, which would lead to improved sustainable development thinking in the first-year engineering programs. Regarding the development of an instrument to assess sustainable development literacy, within the immediate two previous years, the authors have performed prelim studies to 816 students of the first-year engineering program at a large university in the Southwest (IRB ID: IRB2018-1594). Table 1 lists details of the questionnaire© [9].

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. Preliminary questionnaire©

Proposed work

<u>Course development and assessment.</u>

Having accomplished the initial goals of measuring literacy regarding Sustainable Development in first year engineering students, we developed a full semester length course in sustainable development that was offered to sophomore students and seniors. The course had the following identified learning outcomes:

i. Explain the definition of Sustainable Development.
ii. Discuss the most important milestones of the History of Sustainable Development

iii. Identify People, Profit and Planet as the three fundamental dimensions of Sustainable Development.
iv. Discuss the relation of society and the 6th factor (sustainability) in the Engineering Design process
v. Recognize the concepts of Profit—Engineering economics
vi. Recognize the concepts of Planet—Environmental Engineering
vii. Identify that Society (people), Economics (profit) and Environment (planet) most work balanced in harmony.
viii. Discuss Systems thinking for the interdisciplinary approach of Sustainable Development.
ix. Identify the integrated approach of Sustainable development.
x. Explain the concept of Net Present Value for an engineering project.
xi. Recognize the importance of Climate Change consequences in new urban developments.
xii. Discuss the concepts of Life Cycle of an engineering design and Life cycle assessment techniques.
xiii. Explain the concepts of Circular Economy.
xiv. Explain how artificial intelligence (AI) and internet of things (IoT) accelerate circular economy.

While the course was planned for a face-to-face offering, COVID restrictions changed the directionality of development from a face to face to a fully online offering of the course. This will also help in expanding access to other students interested in this topic outside our university. Additionally, we also feel that offering the course in an online format will help us offer the course to working engineers in the industry who may be interested or desire to learn more about sustainable engineering.

For the overall development of the course, we will follow the ADDIE model [10] with the analysis phases driving content and interaction development. We took a modular approach in the design and development, which entailed the development of a series of shorter topical modules that were developed and deployed using a just-in-time delivery model.

The on-line modules were initially planned for a fully asynchronous course, but the need to offer some live contact to students over summer 2020 resulted in the course being offered in a remote synchronous format. But all lectures were recorded and made available in the course, ensuring 24x7 availability of the modules without the need for constant human intervention. Design of the modules followed the principles of multicultural design and andragogy (Parish et. al 2010; Rogers et. al, 2007) [11], [12], [13], thus maximizing the uptake in a multicultural environment.

To ensure that the modules are engaging and interactive, they were situated in Ohl's interaction framework [14], and developed using a combination of interactions developed using specialized software such as Articulate Storyline to create learning pathways through the content. These learning pathways were not fully realized due to the shortened timelines for development due to COVID changes but will be built out more completely for the future offering of the course.

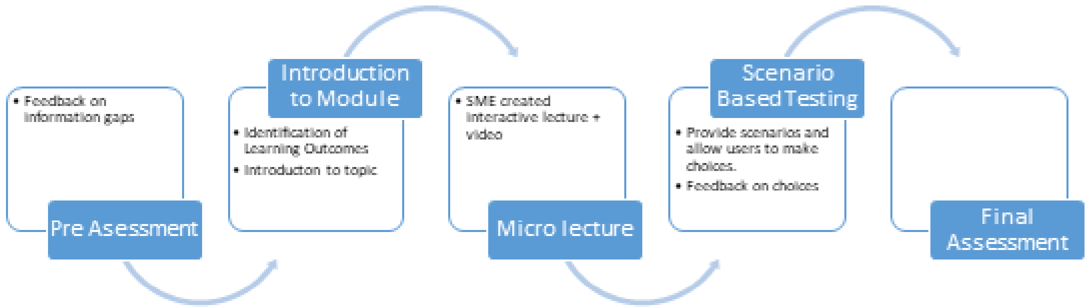

Figure 1: A generalized schematic for learning pathways in the proposed modules

All the content was delivered using our learning management system and we will leverage the data Analytics add-on that will enable ease of transactional use for future developments.

Study Population

This study was conducted over a summer course with two sections. One section designated for senior students and one for sophomore students. Both the courses had the same content, assessments, and assignments, but the senior students had an additional final project where they had to integrate principles of sustainable engineering into an engineering project. The study was equally divided by gender with 7 females and 9 males spread across both the sections.

Methodology for Assessment

We conducted a direct assessment of each defined learning outcome for the course. Each module has an assessment which is aligned to the learning outcome identified for that module. The student performance on each individual assessment was mapped to the defined learning outcomes for the course.

Sustainable Assessment and Sustainable Indicators are framed in the context of sustainable development as a decision-making strategy introducing both fields as well as several essential aspects in a comparable and well-structured manner. Sustainability assessment and sustainability indicators can be powerful decision-supporting tools that foster sustainable development knowledge in first year engineering programs by addressing three sustainability decision-making challenges: interpretation, information structuring, and influence [15].

Results

	Learning Outcome	**Assignment LO is measured in.**	**Average grade**
1	Explain the definition of Sustainable Development.	Lecture 1--HW L-1	100
2	Discuss the most important milestones of the History of Sustainable Development	Lecture 1--HW-L-1	90
3	Identify People, Profit and Planet as the three fundamental dimensions of Sustainable Development.	Lecture 2--HW L-2	100
4	Discuss the relation of society and the 6th factor (sustainability) in the Engineering Design process	Lecture 3 --HW L-3	90
5	Recognize the concepts of Profit—Engineering economics	Lecture 4--HW L-4	100
6	Recognize the concepts of Planet—Environmental Engineering	Lecture 5--HW L-5	100
7	Identify that Society (people), Economics (profit) and Environment (planet) most work balanced in harmony.	Lecture 6--HW L-6	85
8	Discuss Systems thinking for the interdisciplinary approach of Sustainable Development.	Lecture 8--HW L-8	90
9	Identify the integrated approach of Sustainable development.	Lecture 9--HW L-9	85
10	Explain the concept of Net Present Value for an engineering project.	Lecture 7--HW L-7	90
11	Recognize the importance of Climate Change consequences in new urban developments.	Lecture 14--HW L-14	100
12	Discuss the concepts of Life Cycle of an engineering design and Life cycle assessment techniques.	Lecture 10 + Lecture 11--HW L-10 & 11)	90
13	Explain the concepts of Circular Economy.	Lecture 12 + Lecture 13--HW L-12&13)	100
14	Explain how artificial intelligence (AI) and internet of things (IoT) accelerate Circular Economy.	Lecture 15--HW L-15	90

We found that the students performed very well overall in all sections of the course. Two outcome measures (#7 and #9) show a lower performance than others. Examination of these outcomes in showed that students had a harder time when applying the concepts of sustainable engineering in broad contexts and we plan to modify the content to scaffold broader thinking for the future versions of the course. An interesting observation to note was that for outcome measures #7 and #9, female students performed marginally higher than male students.

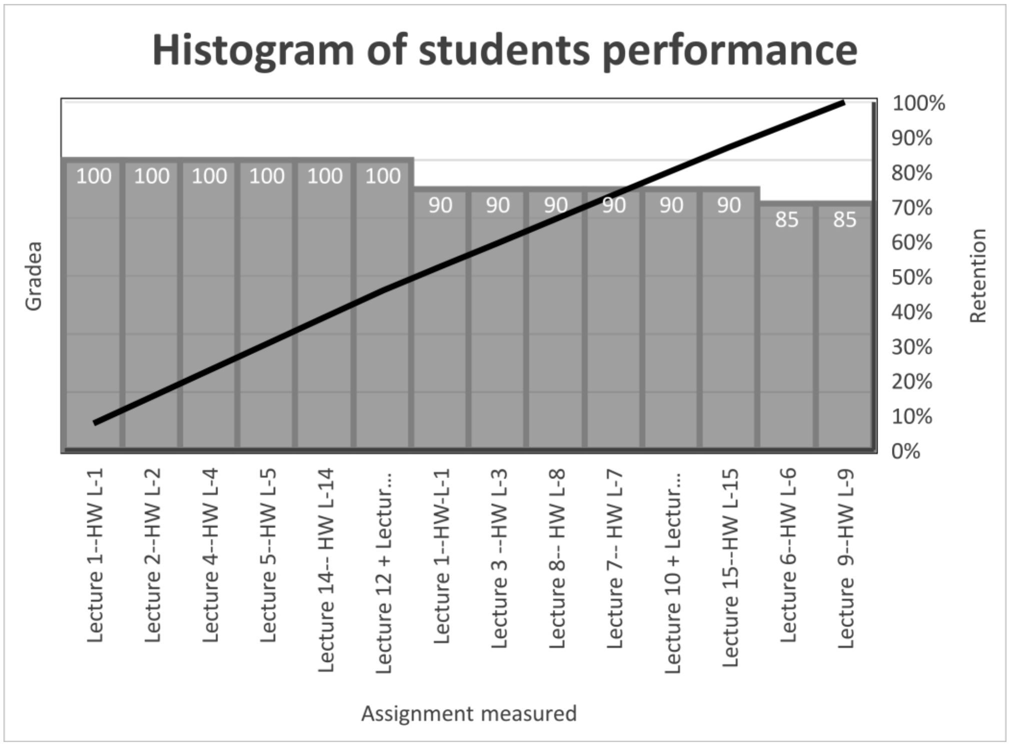

Figure 1. The Histogram of student performance depicts the grades obtained among the students from the indicated material of lectures and assignment. The plot line shows the cumulative percentage of success relative to the total number of assignments. The Pareto 80/20 analysis shows that students consistently succeeded in no less than 13 out of the 15 course modules.

Students were evaluated from 15 HW assignments that constituted 205 questions. One midterm and a final exam. Senior students were additionally evaluated with a final comprehensive project related to their area of interest. The following project titles were chosen by senior students: 1. Life Cycle Assessment of electric vehicles (eV). 2. Life Cycle Assessment of Solar Photovoltaics. 3. Life Cycle Assessment of prefabricated homes. 4. Life Cycle Assessment of Bio Plastic Pipettes. 5. Life Cycle Assessment of Quadrotor Biplanes. All 6 projects received full credit.

Figure 2 depicts the grade distribution between sophomore and senior students in the class. Sophomore students had slightly lower performance than senior students who showed a continued interest and great enthusiasm during the senior projects.

End of the semester feedback also indicates that the students overall greatly appreciated their introduction to the principles of sustainable development and will seek areas for integrating these concepts throughout their education. One telling comment is given below.

I really enjoyed the Engineering for Sustainable Development course and it fulfilled my expectations! I learned SO many valuable things that I am really looking forward to applying to a project someday. I've taken classes that cover environmental sustainability, but I really enjoyed how this course also covered the economic and social aspects of sustainability. I'd be really interested to learn in my senior engineering courses how these ESD principles that I have learned are applied in the engineering area of my interest" (Electrical Engineering Sophomore Student)

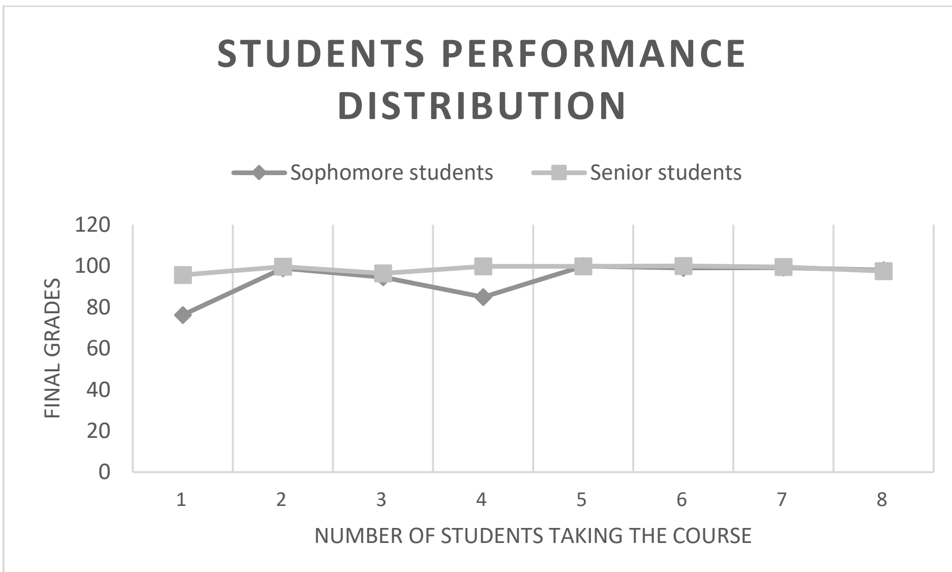

Figure 2. Senior students consistently performed better than sophomore students did. The class was composed of eight sophomore and eight senior students for sixteen students.

Future work

Based on our analysis of the learning outcomes of the course and student feedback we plan to update the content to make the assessments in terms of number of questions and difficulty across the semester. In addition, we are in the process of developing an industry survey to identify specific industry needs that can be mapped to the current course outcomes. This will enable us to take existing content and redesign it using adult learning principles and offer it as upskilling opportunities to industry. In addition, we plan to continue offering the course in Summer 2021 to continue with the development of the modules that was interrupted due to COVID changes. Some future work will also entail following up with senior students to gauge the applicability of the course in their professional lives.

Conclusions.

This paper addresses the identified need for an undergraduate course in Engineering for Sustainable Development (ESD) inspiring new mentalities in engineering students of all majors. In addition, the paper also addresses the sustainable engineering education gap that exits for engineers currently working in the field. The course involves sustainable circular designs as core promoters of a circular economy. This innovative design thinking will create a new mentality in engineering students. The outcomes of the course Engineering for Sustainable Development offered to a balance group of undergraduate engineering students show promising results. This could be a milestone to incorporate formally Engineering for Sustainable Development (ESD) in the curricula of all engineering majors.

References

[1] United Nations (2002) *Report of the world summit on Sustainable Development, United Nations, Johannesburg, South Africa,* 26 August - 4 Sept 2002

[2] JCEETSD (1997) Joint conference report, Paris 1997. UNEP, WFEO, WBCSD, ENPC (1997), *Engineering Education and Training for Sustainable Development*, Report of the joint UNEP, WFEO, WBCSD, ENPC Conference, Paris, France, 24–26 September 1997.

[3] NAE (2005) *"Educating the Engineer of 2020: Adapting Engineering Education to the New Century"*, Committee on the Engineer of 2020, Phase II, Committee on Engineering Education, National Academy of Engineering of the National Academies, Washington DC.

[4] UNESCO *Education for Sustainable Development Goals. Learning Objectives.* Published in 2017 by the United Nations Educational Scientific and Cultural Organization, 7, place de Fontenoy, 75352. Paris 07 SP, France. ISBN 978-92-2-100209-0

[5] N. A. Ashford., Major challenges to engineering education for sustainable development. *International Journal of Sustainability in Higher Education,* Vol. 5 Iss 3. 2004 pp. 239 – 250.

[6] Desha C. J., Hargroves, K., M. H. Smith "Addressing the Time Lag Dilemma in Curriculum Renewal towards Engineering Education for Sustainable Development". *International Journal of Sustainability in Higher Education,* Vol. 10 Iss: 2, 2009. pp.184 – 199.

[7] T. M. Bramald, O. Heidrich, and J. A. Hall., Engineering education for sustainable development, Cambridge, UK. September 22-25, 2013 6(2):203-218.

[8] E. Byrne, C. Desha, J. Fitzpatrick, and K. Hargroves. 2010. "Engineering Education for Sustainable Development: a review of international progress". 3rd *International Symposium for Engineering Education, 2010, University College Cork, Ireland.*

[9] J R Lara, M. H. Weichold, P. Linke., Work-in-progress – Incorporating sustainable development fundamentals in the first-year engineering program. *ASEE Proceedings June 26-28. Montreal 2020.*

[10] Nada Aldoobie . "ADDIE model". *American International Journal of Contemporary Research*. Vol 5, No 6; December 2015.

[11] P. Parrish, and J. A. Linder-VanBerschot, (2010) Cultural Dimensions of Learning: Addressing the challenges of multicultural instruction" International Review of Research in Open and Distance Learning, 11(2), 1-19.

[12] P. C. Rogers, C. R. Graham, and C. T. Mayes, "Cultural competence and Instructional Design: Exploration research into the delivery of online instruction cross-culturally. *Educational Technology Research and Development*, 55(2), 197-217.

[13] Gagne, R., Briggs, L. & Wager, W. (1992). Principles of instructional design (4th Ed.). Fort Worth, TX: HBJ College Publishers.

[14] Ohl, T. M. (2001). An interaction-centric learning model. *Journal of educational multimedia and hypermedia*, *10*(4), 311-332

[15] T. Waas, J. Hugé, T. Block, T. Wright, F. Benitez-Capistros, and A. Verbruggenin Sustainability Assessment and Indicators: Tools in a Decision-Making Strategy for Sustainable Development. *J. Sustainability* 2014, *6*(9), 5512-5534