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Chapter 8. How to Educate Responsible Engineers with Both Eyes Open

8.1. COURSE SUMMARY

Table 8–1

Audience and level of studies	Students (Bachelor)	
Group size	26–50	
Course duration	15 weeks	
Credits	4.5 ECTS	
Workload	Presence: reviewing learning materials 40h Self-study: preparing reports 30h	Total: 70h
Contents/primary topics	• Technological and infrastructure systems (manufacturing, water, energy, power supply, and transportation) • Principles of sustainable development	
Main course objectives	• Applying the principles of sustainable development to analyse the impact of technological and infrastructure systems.	
Main teaching approaches	• Lecture-based learning • Inter-/transdisciplinary learning • Self-directed learning	
Main teaching methods	• Sustainability-related research project • Self-reflection task/exercise • Arts-based teaching and learning method	
Learning environment	Virtual classroom (online learning)	
Link to Sustainable Development Goals (SDGs)	SDG 6 | Clean Water and Sanitation | Ensure availability and sustainable management of water and sanitation for all SDG 7 | Affordable and Clean Energy | Ensure access to affordable, reliable, sustainable and clean energy for all SDG 8 | Decent Work and Economic Growth | Promote sustained,inclusive and sustainable economic growth, full and productive employment and decent work for all SDG 9 | Industry, Innovation and Infrastructure | Build infrastructure, promote inclusive and sustainable industrialization and foster innovation SDG 11 | Sustainable Cities and Communities | Make cities and human settlements inclusive, safe, resilient and sustainable SDG 12 | Responsible Consumption and Production | Ensure sustainable consumption and production patterns	

Table 8–2

Impact assessment:	**(None) Low/ Medium/ High**	**Explanation**
1. Degree of student participation / activeness	High	Conducting own research / documentation, following suggested learning material, and working on weekly activities and a team final project.
2. Degree of student collaboration / group work	High	Participating in a team final project over a whole semester. Students take place in teams and share different perspectives with students of two different programmes: Civil and Mechanical Engineering.
3. Degree of student emotional involvement	Medium	Articulating one's own emotional stance on sustainability-related issues and generating one's own judgment and attitudes regarding sustainable development.
4. Degree of inter-/trans-disciplinarity	Medium	Most learning activities (including the final project) reflect the transferability of applied concepts and methods related to engineering, economy, architecture, social issues, environmental aspects, and ecological impacts, in order to develop a holistic solution approach.
5. Degree of student (self-) reflection	High	Writing weekly reflexive reports about first-hand learning sustainability experiences, critically reflecting one's own knowledge, experiences, assumptions, beliefs, values, personal roles, and attitudes.
6. Degree of experience of real-life situations	Low	Discussing both case studies and final projects based on real-world scenarios focused on solving actual sustainability problems/challenges in both local and global scales.
7. Degree of nature-related experiences	(None)	Virtual classroom learning.
8. Degree of stakeholder integration	Low	One guest lecture about local electric grid by a representative of a stakeholder group in a regional scale.
9. Degree of integration between theory and practice	High	Modules consisting of learning activities providing coherence between theory and practice elements, requiring a direct application of the interaction of such elements.

8.2. COURSE INTRODUCTION

As highlighted by several authors (Ashford, 2004; Glavič, 2020; Perpignan et al., 2020) the increasing universal concern for moving toward more sustainable development practices presents considerable challenges to both education and research. As society becomes more aware of and expresses a greater interest in the challenges of climate change and its impact on society, the academic engineering community must make the transition to incorporating sustainable development principles in the engineering curriculum. This transition is essential to prepare the next generation of leaders in both engineering education and practice (Desha et al., 2009). In this context, engineering education for sustainable development emphasises the need for engineers to play a significant role in developing technically, environmentally, and socially responsible innovations (Byrne et al., 2010). Integrating sustainability fully into curricula and changing the engineering paradigm requires support from leading scientists, faculty and university leadership (Kamp, 2006).

On that line of thought, a Sustainable Development Principles course was developed as part of the 18 foundational basic courses for two Bachelor of Science degrees: in Civil Engineering and in Mechanical Engineering. This course deals with the principles of sustainable development as they apply to engineering systems. Students work in teams to study an engineering system of their choice, learning and applying principles of sustainable energy, materials, and economics in a systems approach to developing a sustainable solution for a given engineering problem.

8.3. LEARNING OBJECTIVES

Table 8–3

Learning objective dimension (UNESCO, 2017)	Operationalization	Competency referred to (Rieckmann, 2018)
Cognitive	Develop a personal definition of Sustainable Development and describe the engineer's responsibility in the process.	Anticipatory competency
	Explain the characteristics of systems thinking and why it is essential to sustainable development.	Systems thinking competency
	Describe the principles of sustainable energy systems and sustainable materials.	Systems thinking competency
	Perform life cycle financial analyses of an engineering system.	Systems thinking competency
	Within a team, perform a sustainability assessment of an engineering system and make recommendations for its sustainable development.	Systems thinking competency
Socio-emotional	Envision change and achieve sustainable transformation starting at a college level.	Anticipatory competency
	Differentiate between needs and wants in the light of Sustainable Development Principles.	Critical thinking competency
	Develop social skills permitting students to collaborate, negotiate and communicate.	Collaboration competency

Learning objective dimension (UNESCO, 2017)	Operationalization	Competency referred to (Rieckmann, 2018)
Socio-emotional	Promote self-reflection skills, values, attitudes, and motivations that allowing students to develop themselves.	Self-awareness competency
	Foster reflection on their own personal belonging to diverse groups (gender, social, economic, political, ethnical, national).	Critical thinking competency
	Encourage thinking and recognition on their own access to justice and their shared sense of humanity.	Critical thinking competency
Behavioural	Reflect on their own individual consumer behaviour considering the needs of the natural world, other people, cultures and countries, and future generations.	Self-awareness competency
	Challenge cultural and societal orientations in consumption and production.	Critical thinking competency
	Plan, implement and evaluate consumption-related activities using existing sustainability criteria.	Anticipatory competency

8.4. COURSE OUTLINE

Table 8–4

Week	Topic	Project milestones
Module1: Introduction		
1	Introduction	
2	Sustainability Concepts	Topics proposed (Challenge choice): Students choose a challenge
3	Systems Engineering	Establish teams (Socialisation): Students meet team members
Module 2: Components of Sustainability		
4	Sustainable Energy Systems	Team agreement (Signature) Students define team agreement
5	Scope and system boundaries	Project proposal (Challenge definition and project component): Students define scope and boundaries of the challenge
6	Sustainable Water Systems	
7	Sustainable Materials	
8	Causal Loop Analysis	Systems analysis (project component): Students perform a causal loop analysis of the system where the challenge is framed
Module 3: Economic Analysis		
9	Time value of money	

Week	Topic	Project milestones
10	Life cycle cost analyses	
11	Economic analysis	Economic analysis (project component): Students complete an economic analysis of the system
Module 4: Engineering Project Application		
12	Project progress meetings	
13	Project progress meetings	
14	Project progress meetings	
15	Final Project Presentations	Final report: Students submit a final report and oral presentation
	No final exam	

8.5. TEACHING APPROACHES AND METHODS

Delivery Methods

This is an online course. There are no scheduled synchronous meetings or lectures during the entire class. There is a weekly schedule of assignments and deliverables where students can dig into cognitive competences by means of several delivery methods like self-reading, case study analysis, and arts-based learning (films and documentaries). Furthermore, students are expected to work in teams to meet the learning outcomes and complete the course project. There are also individual assessments of students' knowledge. Students will develop both socio-emotional and behavioural skills in parallel. Both problem-based and team-based learning have been demonstrated to be high impact pedagogical techniques (Maida, 2011; Kłeczek et al, 2020; Beier et al, 2019; Anwar and Menekse, 2020). Faculty teaching the course have found that these approaches encourage students to engage with the material in a deeper fashion.

Teaching Approach

The typical weekly teaching approach in this course is as follows: All weeks start with a posting of assigned reading and/or video material. Students are expected to read and/or watch the assigned materials and take notes. These assignments cross many disciplines within Science, Technology, Engineering, and Maths (STEM) and sometime include topics outside of STEM disciplines such as art or philosophy. The assignments allow students to tackle several complementary learning approaches dealing with case study-analysis and trans-disciplinary perspective. After completing the assigned readings and/or videos, students are expected to make a thoughtful individual written report on the topic of the week. Additionally, at the end of each week students are given an exercise to assess their individual understanding of the learning outcome for the week.

As a key collaborative learning experience, students are also required to complete a major team project related to sustainable development as the culminating experience for this class. The teams are selected by the instructor and include three or four students. This project requires teams to define a significant engineering problem, identify the system in which the problem is enclosed, perform a system level analysis of the problem, and generate a sustainable approach to solving the problem. Students can choose the problem from a list provided by instructors. The final project asks students to use a biomimetic approach to development of a possible technological problem. This approach creates change of perspective, encourages out-of-the-box thinking, and fosters entrepreneurial skills. The aim is to promote creativity (using a biomimetic view) and enhance engineering project aptitudes (using a holistic view).

8.6. EXERCISES

Typical Weekly Course Structure

Most weeks start with a posting of assigned reading and/or video material on Tuesdays. Students are expected to read and/or watch the assigned materials and take notes. After completing the assigned reading and/or videos, students are expected to make a thoughtful individual written report to the topic of the week by the end of the day on Thursdays. There is an end of the week exercise due on Fridays.

The reports should cover the following two issues:

- Discussion essay (minimum 500 words): write an essay marshalling facts to support or challenge any claim, fact or position taken in the reading or film, or related to corresponding weekly exercise.
- Questionnaire (minimum 150 words per question): answer specific questions or address specific issues related each learning activity, readings, films, or weekly exercises.

Video Assignments

Every week students are given a documentary film to watch as homework assignments (Liu, 2018; Donnelly, 2020). Films are selected to reflect issues that resonate with the students of the Sustainable Development Principles course. The goal is for viewers to leave more informed, inspired and equipped with concrete actions to take in their lives and communities, related to engineering, sustainability, and economy. Every week (on Tuesdays) a documentary film to watch, as homework assignment, will be given. All watching assignments are available online without fees on a streaming platform (as identified in subchapter “Prerequisites”). Homework should be solved handwritten and be turned in by the end of the day on Thursdays in a PDF format.

Reading Assignments

Reading assignments are selected to cover basic factual information (e.g., global energy sources, carbon cycle, financial terminology) or fundamental skills (e.g., life cycle analysis, time value of money computations). These readings are taken from open-source material whenever possible.

Weekly Exercises

At the end of each week (on Fridays) students are given an exercise to demonstrate their understanding of the learning outcome for the week. These exercises are individual assessments. Table 8–5 presents the twelve exercises given to the students. The students had to prepare a written report addressing issues presented in each exercise.

Table 8–5

Week	Exercise	Covered section
1	Degradation of the local natural environment or when tragedy knocks at your door (essay analysing the situation)	Intro to Economics and Sustainability
2	Economic growth and sustainable development: Are they compatible? (essay analysing the situation)	Design for environment
3	Controlling COVID-19 spread on ‘Angelo State’ campus or covering coughs and sneezes and keeping hands clean (essay analysing the situation)	Systems Engineering
4	The future of Texas' power supply or how to prevent downtime and power outages (essay analysing the situation)	Energy systems
5	The future of San Angelo's water supply or how to prevent downtime and water outages (essay analysing the situation)	Water systems

Week	Exercise	Covered section
6	The cheapest water bottle or a simplified Life Cycle Analysis (exercise based on databases)	Life Cycle Analysis
7	How to calculate accumulated costs for an order of tennis rackets (calculation exercise)	Accounting fundamentals
8	Time value of money or how much money do you need to save to be a millionaire? (calculation exercise)	Capital and operating funds
9	Cash flow diagrams or how much does it cost to build a bridge? (calculation exercise)	Financial Basics
10	Investing in bonds or how do process and yields work? (calculation exercise)	Financial analysis
11	The Internal Rate of Return (IIR) method or is the investment a good one? (calculation exercise)	Financial analysis
12	Computational tools for Financial Analysis (calculation exercise)	Financial analysis

Final Project

Students are required to complete a major final project related to a biomimetic design challenge of engineering systems, or in other words, emulating nature to solve technological problems. The final project of this course is developed with an approach based on the premise that nature has been innovating for sustainability for four billion years through the processes of evolution, and there is much to be learned from biological systems about both innovation and sustainable development. Summing up, nature offers a palette of ready-made solutions, waiting for the right problem or need to be expressed. That is what is called biomimicry (*bio*, meaning life in Greek, and *mimesis*, meaning to copy and emulate). The main goal of the project is for students to conceptualize and develop a given engineering design from the three perspectives: sustainability, economics, and project development. The fundamental skills student develop in each of these three areas will be applied in later courses through the curriculum.

The project is scaffolded starting with the project proposal developed in week five, followed by the systems analysis in week eight, and the economic analysis in week eleven. Student teams receive feedback on each of these report parts as they are submitted. The last four weeks of the course are devoted to preparation and presentation of the final report. Both written and oral presentations are required.

As discussed in subchapter "Teaching Approaches and Methods", each student is placed in a team of three to four students. The teams choose and define their own design challenge with instructor guidance. The end product of the project development of a potential approach to solving a technological problem. This final project fosters entrepreneurial skills, encourages a change of perspective, and promotes out-of-the-box thinking. A secondary objective of the final project is to spark creativity and promote an applied engineering vision.

8.7. ASSESSMENT

The weighting system shown in Table 8–6 is used in determining final grade for the course.

Table 8–6

Item	Percent
Homework [Reports]	10 %
Weekly exercises [Reports]	30 %
Project [Component reports, Final report, and Final presentation]	60 %
Total	100 %

Neatness counts! As an engineer and a professional, students´ work often is read and scrutinised by others. In some instances, it could be a legal document or a piece of evidence in a court of law. It is responsibility of each student that the work she/he prepares is presented in a legible, methodical, and logical manner. Homework grades are primarily based on thoroughness, neatness, and completeness.

Students may collaborate to complete the homework; however, each student must turn in his/her own assignment for grading according to his/her own pace (Newton and Salvi, 2020). Direct copying of other's work is not allowed and may be subject to disciplinary actions.

8.8. PREREQUISITES

Academic prerequisite:

- The prerequisite for the course is College Algebra. Specifically, the following math topics are applied in the course: exponents and radicals, logarithms, factoring, algebraic quotients, systems of equations, inequalities, absolute value, and solution of linear equations.

Technology requirements:

- All watching documentary assignments are to be made available to students on a free of charge streaming platform (e.g., Kanopy, Hoopla Digital).

Communications systems:

- Content delivery and online discussion boards: A Learning Management System (LMS, e.g., Blackboard, Canvas, Moodle) is used to deliver all course content both text and video. Course wide online discussion boards were facilitated through the LMS following the guidance of Wikle and West (2019) The schedule and basic schedule and flow of the course is controlled through the LMS.
- Time sensitive faculty-student communications: All faculty use email to facilitate direct, timely communication with students. Some faculty also use social media platforms such as GroupMe® or WhatsApp® for communications with students.
- Collaborative project tools: Google Drive is used to facilitate and document project work within the student teams. Each team is required to create a Google Drive for the course and allow the instructor to join the drive. In this way the instructor can monitor the process and collaboration.
- Online meeting platform: An online video meeting platform is essential for faculty to communicate with student teams and for internal team communications. Selection of an online meeting platform is at the discretion of the instructor. Google Meets®, MS-Teams, and Webex® can be used as well as systems within the LMS.
- Grading: Grading is conducted both within the LMS and using third part grading tools such as Gradescope®, or Turnitin®. The gradebook is kept within the LMS.

8.9. RECOMMENDED RESOURCES

Selected Documentaries for Use in Course:

- Subject: Consumption & Growth

  Scheltema, R. (Director). (2019). Normal is Over 1.1 [Film]. Telekan.

- Subject: Water and Power System

  Hames, M. (Director). (2019). Thirst for Power [Film]. Alpheus Media.

- Subject: Technologies in Human Life

  Walsh, W. & Blacknell, S. (Directors). (2018). The Future of Work and Death [Film]. First Run Features; Journeyman Pictures.

- Subject: Biomass

  Dater, A. & Merton, L. (Directors). (2017). Burned: Are Trees the New Coal? [Film]. Marlboro Productions.

- Subject: Systems engineering

  Cabrera Research Lab (Producer). (2015). Systems-thinking: A little film about a big idea [Film]. Photosynthesis Productions.

- Subject: Humans on the Planet

  Baichwal, J., de Pencier, N. & Burtynsky, E. (Directors). (2018). Anthropocene: The Human Epoch [Film]. Mercury Films; Seville International.

- Subject: Economy

  Pemberton, J. (Director). (2019). Capital in the Twenty-First Century [Film]. General Film Corporation; Upside Production.

- Subject: Rich/Poor

  Round, K. (Director). (2016). The divide [Film]. Dartmouth Films; Literally Films.

- Subject: Climate Change

  Briggs, M. (Director). (2012). Deep Green, Solutions to Stop Global Warming Now [Film]. Bent Image Lab; Deep Green Films.

General Open Resource Material:

- Theis, T., & Tomkin, J. (Eds.). (2018). *Sustainability: A Comprehensive Foundation*. Urbana-Champagne, IL, USA: University of Illinois. https://open.umn.edu/opentextbooks/textbooks/96
- Meadows, D. (1998). *Indicators and Information Systems for Sustainable*. The Sustainability Institute. http://donellameadows.org/wp-content/userfiles/IndicatorsInformation.pdf
- Cal Poly Pomona (n.d.). Sustainable Learning Suite from Linda Vanasupa. *Materials Engineering*. https://digitalcommons.calpoly.edu/mate_fac/
- Linda Vanasupa (2011, February). Series of videos and PowerPoint presentations on sustainable development. https://www.youtube.com/user/lvanasup

Low-cost subscription material:

- Fiksel, J. R. (2009). Design for environment: A guide to sustainable product development. (Second edition.). McGraw-Hill.

Open-source life cycle analysis resources:

- Sustainability Impact Metrics (spin-off of the Delft University of Technology) (n.d.). Idemat. https://www.ecocostsvalue.com/data/idemat-and-idematlightlca/
- GreenDelta GmbH (n.d.). OpenLCA. https://www.openlca.org/

Global energy resources:

- British Petroleum. (2020). *BP Statistical Review of World Energy, 69th Ed* (p. 68). British Petroleum. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
- Lawrence Livermore National Laboratory (2020, May 13). *Everything You Need to Know About the Energy Flowcharts* [Video]. YouTube. https://www.youtube.com/watch?time_continue=53&v=OBuAzxp3EE0&feature=emb_logo
- The Global Climate and Energy Project (n.d.). *Global Exergy and Carbon Database* [Dataset] https://gcep.stanford.edu/research/exergycharts.html
- Lawrence Livermore National Laboratory (n.d.-b). Energy Flow Charts [Dataset] https://flowcharts.llnl.gov/home
- *Exergy Economics* (2015, November 12). What Is Exergy? https://exergyeconomics.wordpress.com/exergy-economics-101/what-is-exergy/

8.10. GENERAL TIPS FOR TEACHERS

Instructors of this course have found that frequent communication with both individual students and student teams is essential, particularly since the course is taught in an asynchronous mode. Similarly, good (virtual) communication among students is necessary. These communications must happen in a way they feel comfortable among peers to express their opinions, doubts, and difficulties, and to generate a sense of belonging to the group. The greater the number of interactions/communications, the greater the motivation and involvement in the learning experiences. Finally, flexibility in the ways support and help is offered is essential to facilitate the learning process and achieve the expected course outcomes.

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