Blueprints for Teaching Ecodesign and Sustainability to University Students

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Abstract

There can be little doubt that if ecodesign and sustainability principles are going to be adopted, a great accelerator would be fundamental curriculum reform in engineering degree-granting institutions across the globe. But for most individuals involved with institutions of higher education, daunting hurdles exist at all levels – departmental, college, university, as well as accreditation by certification agencies. And because of the work burdens extant in academic jobs, most individual faculty members do not have the time to jump through the procedural hoops that would result in real change. Additionally, because of the lack of widespread acceptance of the basic principles of product life cycle management, or the need to take valuable real estate from other topics, most efforts in curricular change end up bogged down. There are a rapidly increasing number of programs that offer some complement of sustainability courses at the graduate level, and some nascent efforts at the undergraduate level. However, the largest problem with single-course offerings is that they effectively pigeonhole "green" engineering into a vanishingly small part of the curriculum, where what really needs to happen is a systemic overhaul of all classes so that ecodesign and sustainability become systemic in the way that engineers operate themselves.

But in order for this to happen, some type of framework must be established that allows both students and professors a larger, more coherent approach to the field. Such a model is presented in this chapter. This approach is both inclusive and extensive. After presentation of the model, this chapter offers the educational practitioner some examples of application of the model – one is a

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model for curriculum reform primarily at the undergraduate level, with examples for potential from the USA, Europe, and India. The other is a template for two more typical sustainability courses that would be offered at the graduate level.

1 Introduction

The origins of this work began with the Dassault Systems Ecodesign Fellowship project. This was launched in 2007 with the appointment of the first author to develop a framework for a coordinated ecodesign curriculum to share across European and US institutions. An assessment of ecodesign education best practices over the past decade indicated that education and dissemination of best practices continued to lag behind method development in this field. For example, a 2001 analysis of the state of implementation of ecodesign in Europe found that ecodesign education was mainly taught at universities in postgraduate education courses.[1] Most technical, design, and business programs failed to provide basic ecodesign education in undergraduate programs. Even further behind lagged smaller academies and schools. The exceptions were large, design-centered technical universities in leading countries, such as the Netherlands, Austria, UK, Australia, and Germany.

Similarly, the state of ecodesign education within North America is fragmented and lacks avenues for dissemination. There are many examples of innovative design educators integrating ecodesign into courses,[2] but engineering education continues to play catch-up. Industry demands for first-year engineers with product life cycle management skills (PLM) continue to grow, particularly in light of the global environmental regulatory environment, such as the Waste Electrical and Electronic Equipment (WEEE) and Reduction of Hazardous Substances (RoHS) directives of the European Union, that will restrict markets to producers who can successfully satisfy the engineering and life cycle requirements in the year 2011.

At the outset of this project, ecodesign education was still playing catch-up. In fact, many of the familiar pockets of innovation were not being disseminated to the wider global engineering education community (see Fig. 2.1). With this in mind, an ecodesign social network in Europe was developed. In order to build a common understanding, a number of practitioners and academics pose the following questions:

- What is ecodesign?
- What is driving ecodesign?
- What is the role of ecodesign in industry, education, government, and research groups?
- What are the barriers to innovation in industry and education, and what are the success stories?
- How do we move toward integration of these areas in order to
  - Improve ecodesign education?
  - Move industry from compliance to innovation?
- What, specifically, can we do as a community of educators, and university-industry partners, to address these problems?

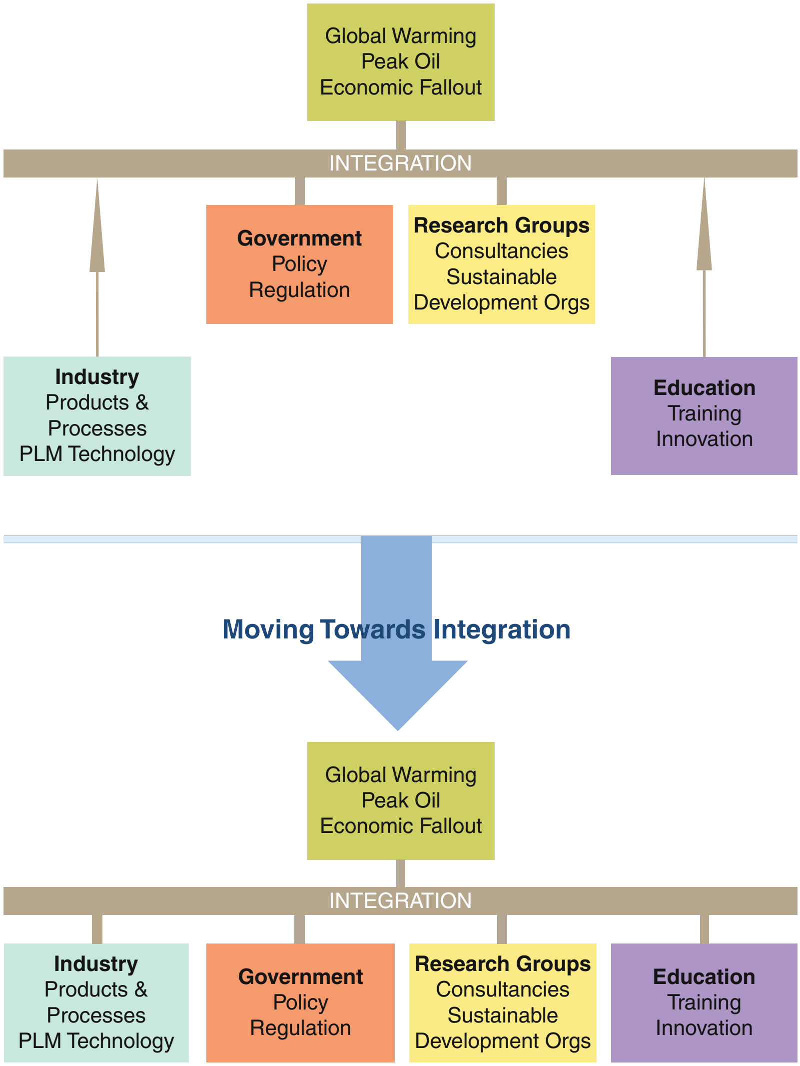

Fig. 2.1 Moving toward integration

2 Background

In the preliminary stages, the current leaders in the field were identified, from both academia and industry, to collaborate on the development of an inclusive ecodesign framework to aid faculty, programs, and institutions in the process of integrating ecodesign into the undergraduate curriculum. Leading institutions served as models to guide the process because they have the highest percentage of specialized education courses, graduate and undergraduate programs, cutting-edge ecodesign research, and university-industry partnerships to support curriculum template development for both existing and emergent programs.

The benefits of an integrated curriculum are twofold: ecodesign and sustainability education in engineering is necessary (1) to make engineering graduates of the future "ecodesign ready" so that they can fill the needs of our future students' employers and (2) to provide the professional development and collaborative opportunities for companies so that industry managers clearly see the benefits of implementing ecodesign and sustainability practices throughout the entire value chain.

2.1 Method

For this project, a survey of institutions and industry partners included collecting sample curricula, video interviews, and casestudies and was compiled in an online electronic-portfolio format.[3] University partners included Delft University of Technology, Technical University of Vienna, Technical University of Denmark, University of Technology Sydney, ETH Zurich, and Washington State University. Industry partners included Priestman-Goode, UK, InterfaceFlor, USA, Engel, Austria, Avaloop, Austria, and OMODO, Germany (see Fig. 2.2).

The data was evaluated across formats. For example, video "mashups" were created from individual footage to answer community questions. Curricula were laid out side by side to compare core competencies, structure, and sequence. Finally, case-study analyses provide a backdrop for understanding the current and future goal state of ecodesign in engineering education and a foothold of inspiration. Finally, a conceptual framework and example curriculum templates from Europe and the United States were developed from the data.

2.2 The Basic Framework

In order to innovate ecodesign and sustainability education, one must first understand what it is. And while there are many potential taxonomies, what we discovered was that often when one talked about participating in either ecodesign or sustainability education, the subject areas were usually one of four categories. These four categories are as follows:

1. Core science, such as the search for a new eco-friendly material.
2. Facilitative strategies, which were often computer tools that made making an eco-friendly choice more likely, or an easier digestion of design trade-offs.
3. Canonical ecodesign philosophy, which offers the designer or engineer a more complete methodology for designing an eco-friendly or sustainable product.
4. Conceptual knowledge, which takes into account that often major innovations in eco-friendliness may occur outside the ecodesign/sustainability framework. For example, the Boeing 787 Dreamliner was not designed at the start to be an eco-friendly aircraft. However, by reducing fuel consumed per passenger mile by

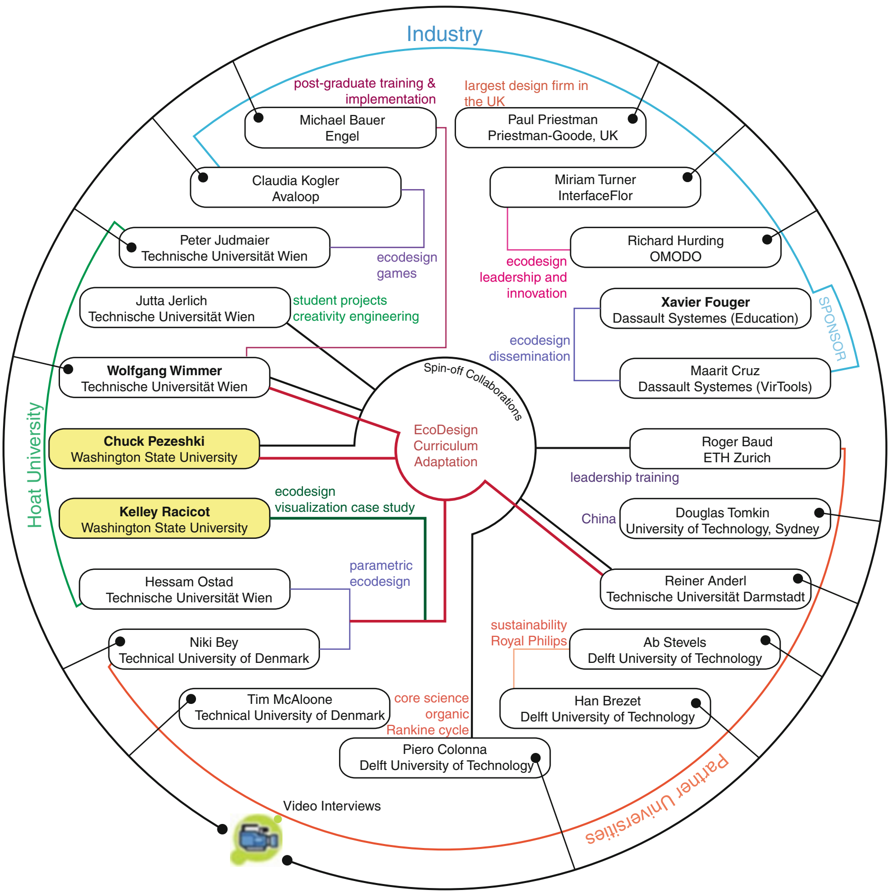

Fig. 2.2 Project partner network map

20%, the resultant reduction of CO_2 emissions from a fleet of aircraft stands to be enormous (see Fig. 2.3).

The following are examples of each category collected during our visits across Europe:

1. Search for a working fluid that fits a Rankine cycle process that can be used for small biomass facilities. This is basic science in that understanding the basic thermodynamics and chemistry are important for developing a system that will promote sustainable behavior on the part of people interested in power generation (Fig. 2.4).
2. Development of tools that will aid in developing a Super-Light car, being completed at the TU-Darmstadt in Germany. This work integrates tools into a conventional Product Life cycle Management system that enables engineers to make decisions that affect sustainability on-the-fly during the design process (Fig. 2.5).

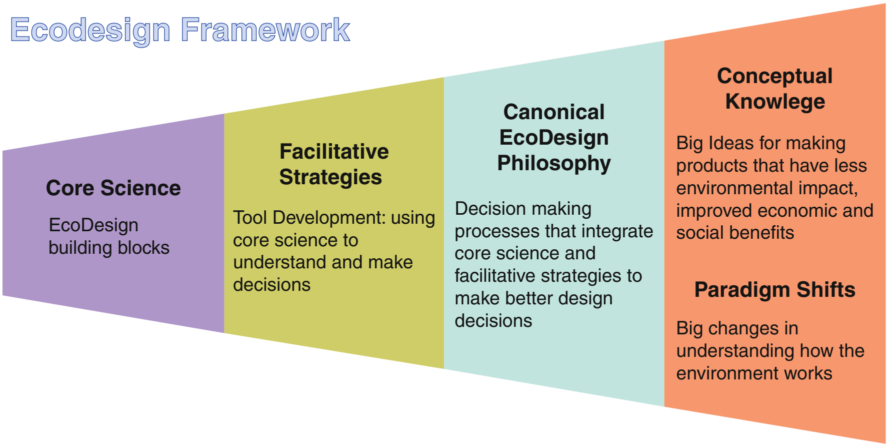

Fig. 2.3 Ecodesign framework

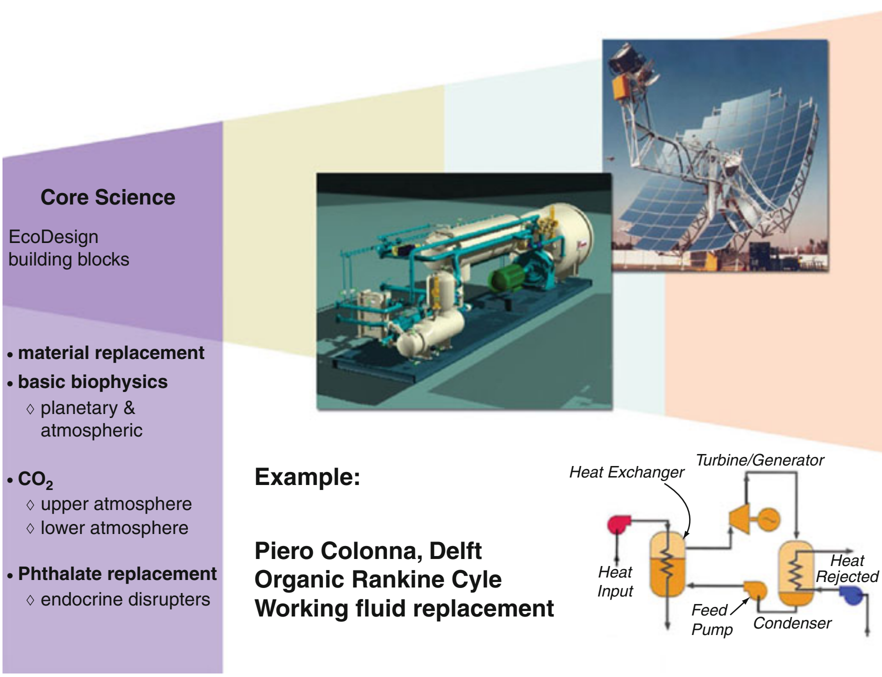

Fig. 2.4 Basic science advances

3. Establishing a process to measure environmental impacts based on all phases of a product's life cycle, by developing systematic ways of looking at use or raw materials, the designed object and its manufacture, its actual use, and (Fig. 2.6). Work being completed at the TU- Wien in Austria is some of the leading-edge work on this in the world.

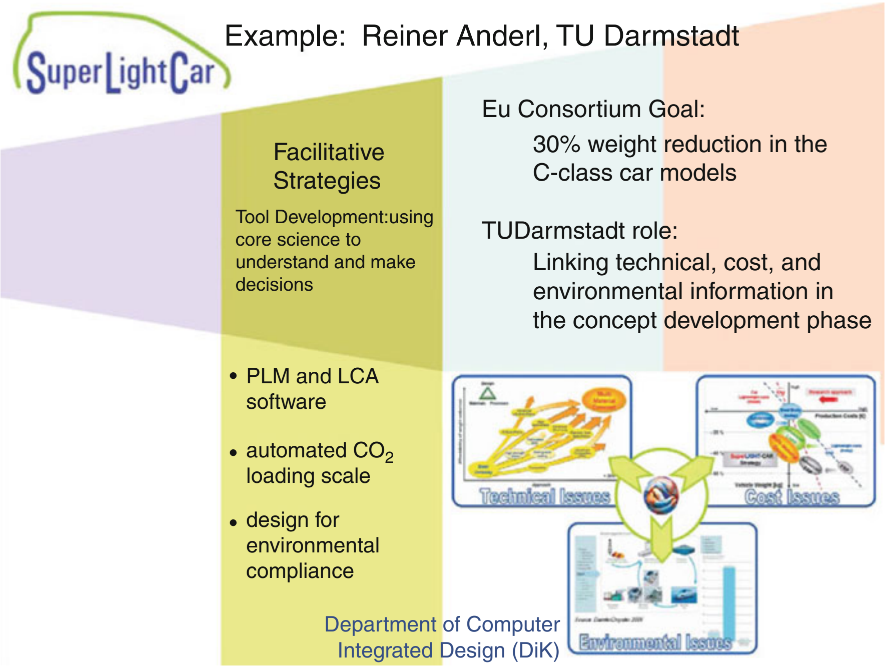

Fig. 2.5 Tool development

4. Back-engineering breakthrough products, such as the Boeing 787, that use 20% less fuel than a typical aircraft per passenger mile, and attempting to apply such lessons across other object/consumer good categories (Fig. 2.7).

2.3 Examples and Modifications

European curricula vary wildly as far as actual ecodesign curricula implementation. However, what we found at even the leading institutions was that ecodesign was mostly relegated to graduate level study. The following figures show what we propose as modifications to the post-Bologna accords B.S./M.S curriculum.

Though there is the perception that Europe is far ahead of the USA in adopting ecodesign, that was not the case. In many interviews and conversations with colleagues, the same level of rigidity as far as changing the undergraduate experience as in the USA was present.

Because of this, modification must occur in actual orientation of the classes within the same basic list of subject matter. What this means is examples, and context inside the standard classes must be changed to reflect an update in design philosophy that favors sustainability. While it might be intellectually desirable to start with a ground-up perspective, this is simply unrealistic in the context of current faculty governance and university administration structures.

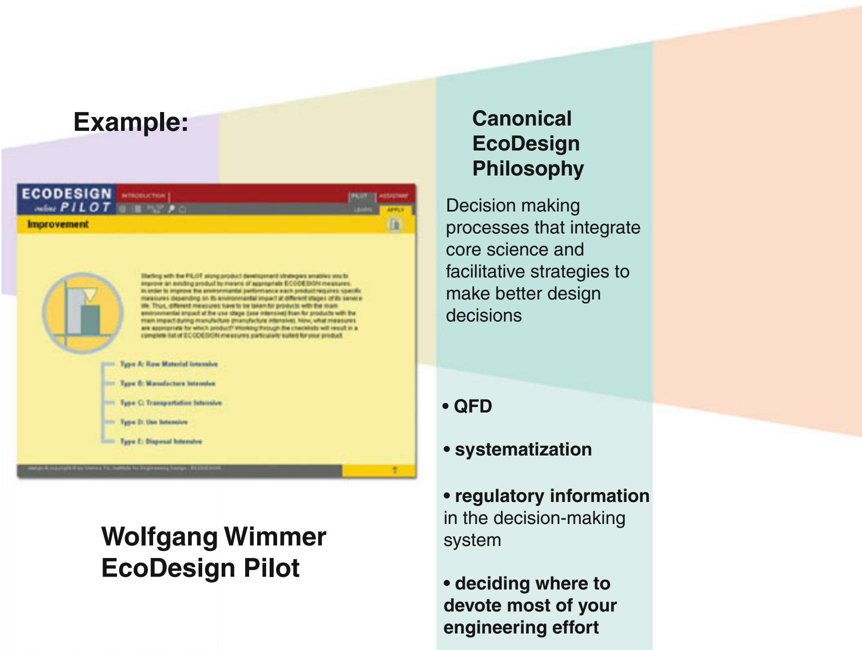

Fig. 2.6 Developing ecodesign and sustainability design processes for consistency

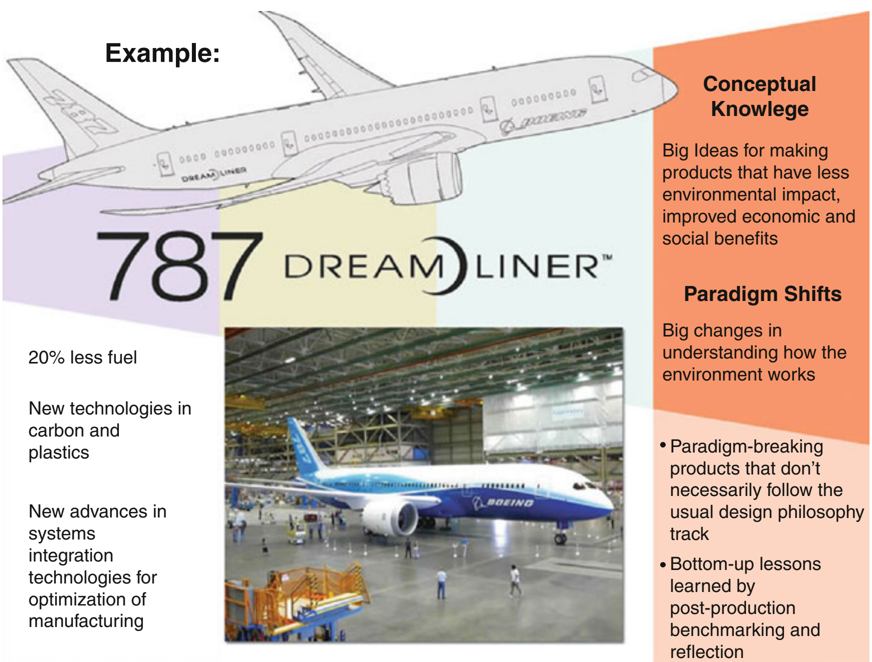

Fig. 2.7 Breakthrough products and back-engineering

The following tables show curriculum modification for a sample US curriculum (Washington State University – Table 2.1), a sample European curriculum (TU – Wien – Table 2.2), and a sample Indian curriculum (derived from the Indian Institute of Technology, Guwahati, India, Department of Mechanical Engineering – Table 2.3), as well as a description of one of the only extant Ecodesign/Sustainability curricula from the Denmark Technical University (Table 2.4). Courses not modified (such as introductory calculus, dynamics, physics courses) are still, of course, required, but are not listed.

There is also no way to, in one short book chapter, lay out an exhaustively structured ecodesign/sustainability curriculum. Rather, the following three tables are more intended to stimulate discussion for how one might start the change process. Please note – these changes have not been implemented, and no representation to that effect is intended. Rather, these three curricula were selected because of the independent experience of the authors with these universities, and their in-depth knowledge of how these curricula function. The final table is reconstructed from an interview and documentation provided by Professor Timothy McAloone, Associate Professor of Product Development in the Department of Management Engineering, Section of Engineering Design & Product Development, and once again is intended to show the thought process of designing an ecodesign/sustainability curriculum – not the verbatim description itself.

3 Graduate Level Study

Graduate level study in ecodesign and sustainability occurs around the world and is voluminous in nature. Because of the inherent flexibility of graduate education – the universal emphasis on a thesis or dissertation, no governing bodies that can dictate particular content, and the rapidly growing interest in the field – the task of designing applicable coursework becomes much more tractable.

A larger discussion on all the potential coursework to be done in graduate education is beyond the scope of this chapter. In fact, an independent course could probably be implemented for every chapter of this handbook. But in the interest of providing templates for universities wishing to implement a course, or courses in sustainability at the introductory graduate level, two case studies, with syllabi, are offered. The first course presents a top-down perspective toward understanding life cycle assessment and sustainability. The second course discusses a bottom-up approach on these same issues.

Earlier in the chapter, various strategies for infusing sustainability topics within existing courses were discussed, particularly at the undergraduate level. If it is possible to include one or two additional courses on sustainability, the key objectives should be:

(a) Understanding the needs and challenges of sustainability in a product life cycle from a systems perspective
(b) Understanding the strategies adopted for systems design for sustainability

Table 2.1 US Mechanical Engineering Curriculum (Sample taken from Washington State University, School of Mechanical and Materials Engineering)

Course	Semester #	Current elements	Modifications
Gened 110 [A] GER World Civilizations 1	1	University general education requirement – history of the world	Influence of environment-material forces on history as a side topic (resource depletion, weather changes, Little Ice Age, emphasis on materials as a key societal definition) Resource Consumption Availability over Time→Books – Guns, Germs and Steel, Jared Diamond
ME 120 Innovation in Design	1	Small-scale projects – Innovation in Design 2 Introduction to engineering disciplines, problem solving, design, teamwork, and ethics	Introduction to PLM – Solids Modeling
Chem 105/115 Chem I General University Requirement	1	Stoichiometry, structure, gases, liquids, solids, solutions, thermodynamics, kinetics, equilibrium, volumetric, and gravimetric analysis	Modification/Discussion of examples to include 25% environmentally related chemical reactions
Chem 106/116 Chem II General Engineering Requirement	2	Acid-base, ionic, molecular, solubility, oxidation/reduction equilibria; kinetics, electrochemistry; systematic chemistry of the elements; coordination compounds	Ecodesign/Sustainability-related case studies for example: Combustion Cycles, Ozone Depletion Causal Chains of events Major Env. Chemical Impact Classifications (IPCC – Int'l Panel on Climate Change)
ME 103 Engineering Graphics	2	CAD/CAM Basics – Orthographic theory, conventions, and visualization; isometric and oblique pictorial; geometric dimensioning and tolerancing, computer-aided drafting and solid modeling	Introduction to PLM – Solids Modeling, Basics of PDM

(*continued*)

Table 2.1 (continued)

Course	Semester #	Current elements	Modifications
Bioscience Elective	2	Understanding biology as a science and its effect on issues within society. Lecture only; not for students majoring in the life sciences	Nanoscale, Chemical Scale, Large Scale Biological Phenomena and their effect on the world and its biosystems Topics such as effects of plastics in ecosystems – phthalates, estrogenizers, Global Warming, ocean impacts and changing climate Causal Chains of Events
EconS 102 Macroecon omics – General Engineering Requirement	3	Theory and policy related to unemployment, inflation, foreign trade, government spending, taxation, and banking	Understanding from a case study perspective on the effects of regulations on economic environments, trade-offs, and cause and effect
ME216 – Integrated Computer Aided Design	3	CAD applications in engineering design and analysis	More case studies of PLM/PDM considerations
Humanities Elective	4	Variety of subject matter, from history to composition, speech, and diversity issues	New Course: Local, State, Regional, National and International Governmental and Regulatory Systems – how they work, stakeholders, case studies of requirements. Voluntary compliance and eco-labeling
ME301 – Thermodynamics	5	Thermodynamic properties of matter, ideal and real gases, work and heat, first and second laws and their application to engineering systems	Cursory evaluation of traditional associated costs (fuel, performance, environment) of all cycles – minor content addition
MSE 201(301) Introductory Materials Science	5	Structure of materials, phase equilibrium, phase transformations, and mechanical properties	Toxicity, environmental impact of select materials for case studies – minor content addition. Eco-data associated with materials – recyclability, real cost of extraction and processing
EE304 Circuits Introductory Circuits Class	5	Basic DC and AC circuits	Case studies of changes in the electronics industry due to environmental regs. Energy Consumption – Standby Issues

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Table 2.1 (continued)

Course	Semester #	Current elements	Modifications
ME 310 Manufacturing Processes with lab	6	Cutting operations, metal forming by deformation, material fabrication, and nontraditional processing	Examination of toxicities of varying metalworking processes. Analysis of by-products from manufacturing processes. Introduction of ideas of Industrial Ecology and parallelization/pipelining of process waste as a supply stream
ME 316 Engineering Design General Engineering Requirement	6	Engineering design process for systems and component; design criteria, creativity, engineering economics, CAD, standards, product safety, design projects	Introduction of life cycle analysis, evaluating environmental impacts of design decisions, conformance to current regulatory environments
ME 401 Mechatronics	7	Integration of mechanical and microprocessor-based systems; control theory implemented with data acquisition system; sensors; actuators, signal conditioning, programmable logic controllers	System monitoring and control regarding energy consumption
Humanities/Social Science Tier III (Upper Level) Elective	7	Numerous choices	Technology Assessment – how technology affects both consumer and societal behaviors
ME 416 Senior Design	8	Integrative design in mechanical engineering; multidisciplinary design project considering both technical and non-technical contexts; organizational dynamics and communications	LCA on all products produced. Ecodesign specifications considered in developing House of Quality. Application of principles developed in ME 316

Table 2.2 Indian Mechanical Engineering Curriculum, Indian Institute of Technology, Guwahati, India, Department of Mechanical Engineering

Course	Semester #	Current Elements	Modifications
Chemistry 101	1	Basic Chemistry	Modification/Discussion of examples to include 25% environmentally related chemical reactions
ME-111 Engineering Drawing	1	Basic Engineering Drawing	Introduction to PLM – Solids Modeling, Basics of PDM
EC-101 Electrical Sciences	1	Electrical Circuits	Case studies of changes in the electronics industry due to environmental regs. Energy Consumption – Standby Issues
BT-101 Modern Biology	2	Basic Biology	Nanoscale, Chemical Scale, Large Scale Biological Phenomena and their effect on the world and its biosystems Topics such as effects of plastics in ecosystems – phthalates, estrogenizers, Global Warming, ocean impacts and changing climate Causal Chains of Events
ME-202 Engineering Materials	4	Introductory materials science	Toxicity, environmental impact of select materials for case studies – minor content addition. Eco-data associated with materials – recyclability, real cost of extraction and processing
ME-301 – Manufacturing Technology	5	Manufacturing processes	Examination of toxicities of varying metalworking processes. Analysis of by-products from manufacturing processes. Introduction of ideas of Industrial Ecology and parallelization/pipelining of process waste as a supply stream
ME-322 Applied Thermodynamics – II	6	IC Engines and Gas Powered Systems	Cursory evaluation of traditional associated costs (fuel, performance, environment) of all cycles – minor content addition

(*continued*)

Table 2.2 (continued)

Course	Semester #	Current Elements	Modifications
ME-498 – Project 1	7	Capstone design	Capstone Project with Sustainability/Life cyle Concepts
ME-498 – Project 2	8	Capstone design	Capstone Project with Sustainability/Life cycle Concepts
Elective Courses (Power Plant Engineering, Advances in Materials Processing, Gas Turbine Theory, Refrigeration/Air Conditioning, Mechatronics, Optimization	7–8		Numerous Course-Specific Opportunities to discuss sustainability/Ecodesign

(c) Getting familiar with the broad sets of metrics and tools for sustainability evaluation
(d) Gaining in-depth knowledge of a few metrics and tools
(e) Understanding how to achieve trade-offs between conflicting objectives in making design decisions

The emphasis should not be on delivering all the available information to the students. Much of the knowledge is not only extensive but also domain-specific. The emphasis should be on creating a solid foundation and providing direction for the students to promote self-discovery. In other words, the emphasis should be on "Learning to Learn." The case studies listed below are the results of these efforts.

3.1 Case Study 1: Systems Design Approaches for Sustainability (Top-Down Approach)

The contents of this course are suitable for an entry-level graduate course or a senior-level undergraduate course. The key segments within the course include:

1. *System Life cycle*: In this first segment of the course, the students are familiarized with the systems design process and the phases in a system life cycle. The systems engineering Vee model is covered. Specific topics within this segment include requirements management, system architectures, and interfaces. This segment provides the necessary foundation for the students to think about the system-wide issues rather than focusing on individual issues in isolation. Tools for systems modeling such as SysML can be included in this segment.
2. *Classification of different sustainability efforts*: In this segment, the students are educated about the systemic needs and challenges associated with sustainable design. A variety of efforts for addressing sustainability are introduced. These include environmental engineering, pollution prevention, environmentally conscious design and manufacturing, design for environment, life cycle design,

Table 2.3 European Mechanical Engineering Curriculum (sample taken from the TU Wien, AT)

Course	Semester #	Current Elements	Modifications
Chemistry for mechanical engineers	1	Electrochemistry and Corrosion, Basic Organic Substances, Lubricants and Additives, Production of Energy, Fuels and Exhaust Fume Treatment	Show how/why chemicals contribute to environmental impact. Impact categories such as global warming, acidification, ozone depletion: how were they caused, which chemicals contribute to each impact category and why; chemical reactions
Fundamentals of Manufacturing Engineering	1	Overview of production technologies as a basis for understanding life cycle modeling	Influence of material choice to manufacturing technologies, impact of manufacturing technologies, Introduction of manufacturing as part of the product's Life Cycle; impact of manufacturing processes
Fundamentals of engineering design	2	First intro of Ecodesign; basics of design as a prerequisite to understand product development and possible product improvements	Where and when to start with Ecodesign, introduction of Life Cycle thinking, introduction of implementing environmental aspects into product development. Introduction of different tools such as QFD, TRIZ could be possible
Machine Elements and design classes	3	Further design specialization in machine elements	Including Life Cycle thinking into design and design concepts, the cases to be designed by students could already include Ecodesign-based calculations and methodologies, Life Cycle Assessment for parts and larger assemblies
Fundamentals of electronics	3	Components of electronics, optoelectronics, sensors and digital technique and power electronics with practical applications	Standby consumption and relation to electronic circuits, how/why does standby occur, Introduction of directives related to electronic design, etc. (EuP, RoHs,. . .)

(*continued*)

Table 2.3 (continued)

Course	Semester #	Current Elements	Modifications
Fundamentals of Material Science	3	Material categories, material properties, different material data	Introduction why/how material production contributes to environmental impact; in a context of Life Cycle thinking: material choices related to design concepts and further environmental impacts
Production Management	4	Process engineering, organizational aspects in companies	Pointing out relation between applying Ecodesign and changes/visions in the structure of organizations, maybe also cost-related discussions, discussions of where to start to apply Ecodesign in companies, outlook, time frame
Applied thermodynamics	5	Energy sources, power plants, generation of energy – understanding basics of energy concepts	Introduction of alternative energy sources, energy outlook, an introduction what assessment methods such as the cumulative energy demand means, regional and global energy outlook
Non-metallic Materials	5	Polymers and inorganic materials – understanding material properties	Same as fundamentals of materials: Introduction to why/how material production contributes to environmental impact; in a context of Life Cycle thinking: material choices related to design concepts and further environmental impacts
Basics of Managerial Accounting	5	Life Cycle Costing (LCC)	Relating LCC to LCT, introduction of Ecodesign and its commercial benefits

industrial ecology, and sustainable development. In this segment, the focus is on making the students aware of the scale and scope of different efforts and relationships between them. The focus is not on providing the details of each effort.

Table 2.4 Denmark Technical University, Ecodesign Curriculum

User-oriented design	1	This course is aimed at having the students critically assess a particular design method, through the study and use of the particular method of their choice. The idea is to help them understand how professional design methods are created and used, and how the success of a design method is highly dependent on its domestication in the adopting organization. This course is often carried out with a company. Although environmental issues are not specifically the aim of this course, the choice of an ecodesign tool could easily be the object of a student project here. A selection of the learning objectives follows: • Carry out an empirical investigation upon the use of methods and work routines in a concrete practice • Write and present a report of the observations, conclusions, and the work process during the investigation • Establish and specify a concrete delimitation and characterization of such a method or routine • Understand methods and routines as modeled, normative competences used for the rationalization of social processes • Create insight into the domain and the organization, where the investigated methods are used in practice • Understand the actors and articulate traits of the actors and their interpretations of the application of the method, its motivation, purpose, goal, and expected results • Identify different types of methods and characterize their properties, conditions for their application, and effects related to this application. Explain and reason for the used field study methods used by the investigation of the methods use in practice, for instance, observation technique, interviews, etc.
Product usability and design	1	This course sets the theoretical framework for the students' treatment of product life issues and socio-technical understanding – not least the understanding of actor-networks and their influence on a product's general life cycle. The course also acts as the theoretical framework for 42010, the project-based course. Again I have selected the following from the course's formal learning objectives in order to pinpoint the areas I feel are of relevance for environmental thinking: • Understand products and technologies as socio-technical artifacts. • Analyze products in societal contexts and as part of the society. • Analyze the use of products in different contexts. • Analyze products and technologies in relation to life cycle and market.

(*continued*)

Table 2.4 (continued)

Product analysis and redesign	2	As opposed to the previous two courses, which foster a stakeholder-oriented view on products and their use, this course takes a technology-view of products. The students are presented with a series of products (one per project group), which they should carry out a technological postmortem on. They should understand why particular components were placed where they were, who decided which manufacturing process for this particular module, etc., and at the same time understand how to describe and structure a product. Although it is not a direct aim of this course, to analyze the product in terms of its environmental "contents," the students become competent in understanding products' anatomy and the relevant processes connected to producing the product. A selection of the course's learning objectives follows: • Describe a product's structure, mode of action, and embodiment (mode of action analysis). • Describe a product's manufacturing and assembly (manufacturing analysis). • Identify the socio-technical context, which the product is part of, and clarify the assignment of meaning in use through interview with and observation of different actors (user analysis). • Select and detail solutions considering functionality, manufacturing, and use. • Argue for value in use based on the change in the socio-technical context. Redesign a product based on the relevant analyses and the proposed alternative solutions.
Industrial design	3	This course trains the students in the activity of design synthesis, from an industrial design perspective. Relating these competencies to ecodesign, these are important in relation to the ecodesign synthesis activity – not least as ecodesign solutions are often embodied in alternative aesthetic forms. Selection of learning objectives follows: • Identify design-related problems and needs in target groups • Formulate a design brief • Select and apply relevant visual communication tools in the different phases of the industrial design process • Describe and apply basic design method
Design of work processes	4	These courses look at the workspace as the design object. Workspaces are understood here in the broadest sense – from hospitals, to factories, to stations, to shops, and so on. Physical working environment is an integral part of ecodesign thinking in Scandinavia, which makes these two courses relevant for the students' environmental competencies. Furthermore, these courses foster the thinking of the activity as the design object, rather than merely the artifact (which aids in later teaching about functional units, customer activity cycles, and PSS). Environmentally relevant learning objectives of both courses, which are closely linked to each other are as follows: • Make use of models, prototypes, and mock-ups in participatory design processes • Develop basic design solutions considering different criteria: ergonomics, efficiency, and quality • Make use of the "reframing" concept in reflecting upon a design process • Give an account of the work environment concept Accomplish a basic work environment assessment in a company

(*continued*)

Table 2.4 (continued)

Product/ service-systems [project-based course] (elective)	5–6	The aim of the course is to give students experience in using tools for product life design through a project based on a product or service system case. All of the examples used and projects carried out by the students in this course aim toward creating radical environmental improvements to the provision of a certain functional unit. Learning objectives: A student who has met the objectives of the course will be able to: • Identify and account for relevant environmental issues related to a product or a service • Analyze and assess environmental impacts of a product in a life cycle perspective • Describe the social and institutional conditions of product-related environmental issues • Carry out a systematic mapping of a product life by using adequate tools to describe actor-network relations, users, and activities • Establish a product life gallery which integrates contributions and trade-offs between the above mentioned elements • Consider opportunities of improved environmental performance through combining product and service approaches • Synthesize an environmentally improved solution as a product/service concept Use scenario methods to identify the necessary conditions for the implementation of a concept
Product life and environmental issues [theory-based course] (elective)	5–6	This course is where the students are explicitly introduced to environmental issues and theories. The students are trained in thinking environmental issues into their product designs, on a level par with other dispositional (DFX) considerations (e.g., quality, cost, manufacture, risk, etc.). The course has the following main goals: • To give insight into strategies and tools for handling environmental problems in connection with the design of products and product life systems • To introduce environmental issues into the activity of product life design • To identify and analyze relevant environmental and resource-related problems and their regulatory origins • To analyze product life cycles, especially with respect to the involvement of relevant stakeholders • To use methodical tools for product life–oriented design (DFX) with a particular focus on ecodesign • To generate scenarios and strategies for the realization of improved environmental situations, in relation to products and usage situations

(*continued*)

Table 2.4 (continued)

	Learning objectives: A student who has met the objectives of the course will be able to: • Master life cycle thinking and product life thinking • Identify product life cycles, stakeholders, resource- and environmental goals, and to understand product life–oriented quality and total life costing • Identify product chains as social and material frames • Recognize and understand environmental and resource problems and their material, economical, and political backgrounds • Demonstrate knowledge of environmental regulation and understand its effect on the incorporation of environmental aspects into design processes • Master methods for the analysis of product life systems, for example, MECO • Master methods for the modeling of "meetings" and "universal virtues" and to understand DFX and related tools, structure, and contents Operate at various levels with respect to environmentally-oriented redesign; emissions, materials, process, production, product, consumption, system, etc.

3. *Strategies for systems design for sustainability*: In this segment, the focus is on providing details of a few approaches for sustainable design. Specific guidelines and steps are discussed. Examples include product system life extension, material life extension, material selection, reduced material intensiveness, process management, efficient distribution, and improved management practices. This segment can be linked to a project or an assignment. Specific decisions and associated trade-offs are identified.
4. *Metrics and Indicators*: Within the context of sustainable design decisions, this segment focuses on metrics and indicators for quantifying the impact of different design alternatives on different environmental factors. Frameworks such as Eco-Indicator 99 and ISO 14031 Indicator Framework are discussed in detail.
5. *Specific sustainability tools*: The emphasis in this segment is on core tools used in sustainability such as Life cycle Analysis (LCA) and Life cycle Cost Analysis (LCC). These tools are covered due to their breadth and domain-independence. The students either can use these tools for their projects or can include an assignment.
6. *Multi-attribute decision-making frameworks*: Since systems-level sustainability decisions are invariably associated with trade-offs, the role of systematic multi-attribute decision making is significant. In this segment, decision-making frameworks such as Utility Theory[6] are covered. The students are educated about mathematically rigorous ways of modeling preferences, alternatives, and

attributes. Systematic accounting of uncertainty within design decisions is a key aspect of this segment.

The course is particularly suitable for project-based learning. The students can be assigned a project at the start of the semester. Each segment can be associated with an assignment that can be scaffolded toward the achievement of goals of the project. This systems-based approach toward sustainability education equips the students with the necessary tools and provides them a foundation on which they can continue learning.

3.1.1 Tentative Course Syllabus

Weekly schedule:
Week 1: Course overview, Design process
Week 2: Overview of systems engineering life cycle process
Week 3: Requirements management in system design
Week 4: Architectures and interfaces for systems design
Week 5: Overview of model-based systems engineering and SysML
Week 6: Sustainability in systems realization
Week 7: Design for environment
Week 8: Metrics and indicators (Eco-Indicator 99)
Week 9: Life cycle analysis (LCA)
Week 10: Economics considerations – Life cycle cost (LCC)
Week 11: Socially responsible design
Week 12: Decision making in systems design, Utility theory
Week 13: Multidimensional decision making under uncertainty
Week 14: Research topics
Week 15: Project presentations

3.2 Case Study: Sustainability Assessment for Engineering Design (Bottom-Up)

In this course, the focus was kept on addressing sustainability assessment at the design stage of a product. In the design stage, a product is not only planned for its use and manufacturing but also maintenance and disposal. Therefore, the basic introduction to the course should include educating the students about engineering design and planning. After laying down the basics of engineering design, the next aspect to discuss would be sustainability, its meaning, and various aspects related to it. Although sustainability is talked about as triple bottom line of economy, environment, and society, it can only be achieved by developing and utilizing the right technology in a right manner. Therefore, the triple bottom line should be viewed with a technological lens.[7]

The next step is to introduce economic, sociological, and environmental aspects. Economic aspects are taught in many undergraduate engineering design courses, so these aspects will not be discussed in this course. Environmental aspects are considered by learning about Life Cycle Assessment and discussing various labeling and regulatory standards for products. Societal aspects relating to sustainability should also be discussed. By combining economical, environmental, and societal aspects one can develop a method for sustainability assessment of a product/design. Since all of these aspects introduce new constraints on product design, these can be viewed as boundary conditions to an optimization. Therefore, the course should also include optimization techniques and effects of uncertainty on developing an optimal design of a product.

Thus, the course will consist of five core components that will be covered in the following sequence: (a) Engineering Product Design and Planning, (b) Life Cycle Assessment, (c) Standards for Sustainability, (d) Sustainability Assessment, and (e) Uncertainty and Optimization techniques.

The objectives of the course will be as follows:

1. Ability to consider sustainability as an integral part of the design process
2. Advanced knowledge of sustainable product design
3. Ability to perform Life-Cycle Assessment for a product
4. Ability to mathematically formulate optimization problems accounting for uncertainty
5. Gain an understanding of the state of the art in sustainability assessment of products

3.2.1 Learning Assessment

The course will consist of homework, online research and reading, minor project, and a major project. The minor project will focus on Life Cycle Assessment of a product using traditional methods available. The major project will consist of a sustainable engineering design project, where the students will consider uncertainty and optimization while solving a sustainable design problem for societal benefits.

3.2.2 Tentative Course Syllabus

Weekly Schedule:
Week 1, 2: Engineering Product design and planning
Week 3: Sustainability
Week 4–6: Life-Cycle Assessment
Week 7–8: Standards for Sustainability
Week 9–10: Sustainability Assessment
Week 11–12: Optimization and Uncertainty
Week 13–14: Formulating and designing optimal sustainable product
Week 15: Discussions and work on project

4 Conclusions

Ecodesign and Sustainability advances are being only slowly integrated into undergraduate curricula around the world. In order to improve the rate of dissemination, two things must occur: First there must be a clear taxonomy of what is actually meant by ecodesign and sustainability. Second, what must occur is that faculty in these areas must take a pragmatic approach toward adoption by re-engineering and adapting current courses to give a focus across the curriculum toward the concepts in ecodesign and sustainability, instead of working to add new courses. Finally, if the only immediate alternative for introduction of this type of material into the curriculum is the addition of another course, two potential courses are offered for discussion. This chapter is hopefully a small step forward in providing discussion jump-off points for all these larger directives.

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