TEACHING INDUSTRIAL ECOLOGY WITHIN THE FACULTY OF ENGINEERING OF UNIVERSITY OF BRASILIA

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Abstract. *This paper describes the first two semesters' experience within the Faculty of Engineering of the University of Brasilia with the Course on "Introduction to Industrial Ecology". The proposal for this initiative, within the Engineering courses of the Brazilian universities context, was made at the beginning of 2002, in response to expanding needs for providing environmental management knowledge to the professionals graduated at the Engineering courses.*

Keywords. *industrial ecology, environmental education, graduate education, interdisciplinary learning, system thinking*

1. Introduction

Industrial Ecology (IE) has been discussed conceptually during the last 30 years, however the several attempts made in that direction mostly remained marginal. Only in the early 1990s the expression re-appeared, among a number of industrial engineers within the National Academy of Engineering in the USA.

Since than there is not yet a standard definition of industrial ecology and several authors make no difference between industrial metabolism and industrial ecology. In fact, industrial ecology aims at a much broader perspective than only assessing the use or the minimization of waste generation. Industrial ecology aims at the integrated management of all resources within the scientific ecology concept, and thus incorporating the also recent development of the concept of ecosystem.

Otherwise, industrial metabolism stands for the whole integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes in a (more or less) steady-state condition. The production (supply) side, by itself, is not self-regulating. The stabilizing controls of the system are provided by its human component. This human role has two aspects: (1) direct, as labour input, and (2) indirect, as consumer of output (i.e. determinant of final demand). The system is stabilized, at least in its decentralized competitive market form, by balancing the supply of and demand for both products and labour through the price mechanism. Thus, the economic system is, in essence, the metabolic regulatory mechanism(Ayres and Simonis, 1994).

In that sense, industrial ecology is industrial when it focuses on product design and production processes, and as an important source of environmental burdens, although this is not an exclusive position. Industrial ecology is also ecological when it models industrial activity as a non-human ecosystem, and when it locates all the human technological activity within the context of the larger ecosystems that sustain it, analyzing the sources of resources used by the society and the sinks able to absorb the waste generated by this society.

In others words, through the lenses of the industrial ecology concept, and the tools being developed to put into practice this theory, economic systems are viewed in concert with their surrounding systems, and not disconnected from them. (a recent description of IE and its concepts and uses can be found in Ayres and Ayres, 2002)

Due to these expanding needs for augmenting environmental management knowledge applied to industrial management, it was proposed at the beginning of 2002 the Course on "Introduction to Industrial Ecology", within the Faculty of Engineering-FT of the University of Brasilia-UnB.

The main target is to offer engineering professionals with a broad conceptual and practical framework on environmental management issues, and to provide significant new contributions to scientific knowledge in the interdisciplinary area of environmental management, environmental impact evaluation tools and sustainable development.

In fact, knowledge in these areas is essential to managing an institution within a conformity model. However, the knowledge to create greater efficiencies and new business models that resonate with a sustainable enterprise was not being presented and explored. Based on this assumption, it is needed to differentiate the program and shift the curriculum from one that solely presents traditional courses to a curriculum that includes the creative and proactive integration of an environmentally conscious model of sustainability with the business model.

Therefore, it has been introduced this course on industrial ecology concepts that redirect the program toward a model of proactive assertion of strategies that expand the role of environmental management in an organization. The approach moves from managing environmental effects at the end of the pipe and on the factory floor to one that includes participation with strategic planning, marketing, product design/development and all the others levels of management. Moreover, it emphasizes the perception of environmental management as allied with strategic concerns of the enterprise as opposed to an internal representative of regulatory imposition.

2. Main Motivation

The main motivation for the introduction of the discipline of Industrial Ecology in the graduation in Mechanical Engineering of the University of Brasilia - UnB consists of promoting the discussion of the questions of sustainability of previous models of development in the modern society. Moreover, this fact will endow the future graduated Mechanical Engineering with techniques of quantitative analysis that allow him to support his management acts within the society.

These questions are basic to frame development models for the future, and necessarily, to support management acts on the context of a society in continuous and accelerate transformation. As example of this trend, the study elaborated in 1996, in the United States of America, by a committee nominated for president Clinton to analyze the models of development for the future concluded that on the current models of development:

The economic, environmental and social problems cannot be separately addressed. The economic prosperity, the environmental quality and the social equity, must be simultaneously considered.

- Any system of environmental protection must be based on scientific criteria that consider environmental impact of processes and services.
- Regulations with technological support must benefit solutions of preventive type rather than reactive solutions that control pollution after its formation.
- Social science, economy and values must be in the bottom of the decision making process. The availability of reliable information is essential for the process of strategic planning.

In this context, the committee suggested the following criteria that must guide the processes of decision taking, in the next decades:

1. To extend the responsibility on the product.
2. To establish new forces of market and to enable its use.
3. To encourage the development of environmentally-friend technologies.

The international recognition of this type of reflection motivates its introduction in the courses of Mechanical Engineering. In this context, the main objective of this discipline consists on the discussion of new models of development and of the education on new techniques of environmental and energy analysis whose application can supply excellent information to the industrial management activity, in a context of sustainable development.

The establishment of links between environmental analysis techniques and industrial management, through operational research techniques, constitutes an enclosed innovative aspect in the discipline syllabus. The establishment of this integration through quantitative methods of analysis, allows maximizing the efficiency of the productive processes, considering simultaneously the cost of the externalities associates with the environmental impact of the industrial products during its life cycle, and its added value to the environmental policies, specifically based on eco-taxes or environmental regulation.

This issue constitutes in a research and development area this discipline is particularly motivated.

2.1. Scientific - Pedagogical Motivation

The main scientific motivation on teaching Industrial Ecology concepts consists of establishing a scientific support to the relationship between energy and environment issues and the Industrial Management.

This discipline conjugates in its program a global and combined vision of the concepts of Energy and Environment, Environmental Economy and Industrial Management, attributing great emphasis to the analysis methods of these problems, namely Life Cycle Assessment - LCA, Material Flow Analysis – MFA and Environmental Input-output Tables – EIOT.

The inherent inter-disciplinarity of this course constitutes the strongest scientific motivation, in the sense that it involves the development of quantitative methods of analysis of complex problems.

The pedagogical motivation of this course arises from the link it carries out between the economic theory, the energy and environmental analysis and the socio-economic actuality. These links move the student from a University-context to an industrial context, which is highly stimulating for the undergraduate in Engineering.

The pedagogical interest thus is empowered by the several discussions carried out during the classes, namely:

a) Application of the basic knowledge acquired to assess problems of real interest, related with the energy management and the respect with the environment.

b) Application of the knowledge and techniques acquired to analyze industrial problems.

c) Development of capacity of argument, work in group and elaboration of technical reports.

2.2. Technological Motivation

The environmental regulation constitutes a threat and an opportunity for industry. During a first phase, the industry looked for equipment to deal with its pollutant effluents, and therefore satisfying the legislation, what constitutes a threat to its activity by increasing its costs. In a second phase, the industry stimulated research activities on the development of new techniques of cleaner production (for instance, eco-design), creating business opportunities with high added-value and reduction of production costs.

This process can be associated with a change towards an economy technology-driven and based on the information transfer, in which the relation between efficiency, profit and environmental protection is well-known. The notion of that pollution and residues are, in the industry, associated with inefficiency and, therefore, with extra costs, is nowadays already understood. The change of attitude of industrial managers to respect with the environment constitutes the main technological motivation of this discipline, whose content will contribute to support processes of decision making within the new industrial management, an issue already addressed by Mulder (2000a) and Mulder (2000b).

In this context, the student of Mechanical Engineering is particularly able to act as manager of environment-driven technological innovation, and this discipline, developing new concepts and techniques of analysis, improves his capacity of decision making, aiming at the sustainability of our society.

From the point of view of the lecturer, there are also important issues to be addressed but this will represent another paper. I suggested the reader to start exploring the work by Bras-Klapwijk et al. (1999), and their experience at the Faculty of Engineering of the Delft University.

2.3. Guiding Principles for the Implementation of Industrial Ecology at FT/UnB

The process of establishing this interdisciplinary approach within the Faculty of Technology-FT/UnB proceeded parallel, and in close connection, to the process of establishing industrial ecology at the post-graduate courses of the Center for Sustainable Development-CDS, a locus of multi-disciplinary studies within the University of Brasilia. However, in this latter institution other internal and external interests were much more significant in the process, somewhat similar to the process occurred at Norwegian University of Science and Technology (Marstrander et al., 2000).

During these two first semesters this initiative has received significant support from the others Engineering courses' coordinators. This support allows establishing an organizational framework, based on guiding principles for the development of industrial ecology at UnB, namely:

- At the beginning, to start with a particular collective activity, i.e., a student course at the undergraduate level, to promote involvement across different FT/UnB courses, and therefore recruiting students from 5 technological courses;
- To stimulate studies to be case-oriented. Using life cycle related projects, the students should work in teams and assume different roles within a specific project, contributing on the basis of their own academic specialization. One special issue is the need to include economics and social sciences in addition to the more obvious technical disciplines;
- Of special importance to achieve a long-term success could only be secured through research-based activity. On this regard, all classes activities should theoretically and methodologically be developed in close collaboration with Master of Sciences and Doctorates theses being carried on at others departments, and mainly at CDS;
- A main focus of attention is done on LCA methodology and on accessing an LCA laboratory with customized databases, being developed taking into account different materials and manufacturing processes. In this context, it is seek a strong relationship with the research staff and industrial partners;
- Also industrial ecology is strongly related with governmental activities, and on this matter CDS partnership plays an important role;
- At least, the establishment of international alliances will be actively looked for, and in a first moment this should be done through seminars and exchange of ideas on teaching and research. Particularly, the International Society for Industrial Ecology-ISIE conferences, the Gordon conferences, the UNEP LCA Initiative Seminars, Ecobalance meetings, are some of the main forums of discussion.

Otherwise, simultaneously to those principles, and to the need for specific teaching resources and methodologies, it is expected barriers to teaching Industrial Ecology (see also Cooper and Fava, 2000), namely those described by three categories:

1. administrative barriers;
2. application barriers, mainly the use of IE concepts within a context of professional practice based on federal government policy makers environment, as the one meet at Brasilia, the capital of Brazil;
3. the lack of statistics usually needed to perform those IE environmental impact analyses, based on regional-customized data bases.

3. Subjects on Industrial Ecology

In this section, Industrial Ecology related subjects currently taught at the Faculty of Technology of the University of Brasilia-FT/UnB are presented. Syllabus, as well as some examples of project topics, is given. The context of the course (one semester) and the total number of hours are also discussed.

First of all, despite the fact this course is made available through the Department of Mechanical Engineering, students of all the five Engineering areas of the Faculty of Technology are allowed to attend the course. In this context,

Mechanical, Mechatronic, Civil, Electric and Electronic and Forestry Engineering issues are present at the discussion within the classes. This multidisciplinary environment creates a very stimulating atmosphere during the classes, allowing a special condition to each undergraduate student from one department starts taking into account other issues and amplifying his field-of-vision of entrepreneurial management matters.

Detailed information of the syllabus of this course is presented hereafter:

1. Introduction to industrial ecology

A. The Concept of Industrial Ecology – an historical evolution of pro-environment entrepreneurial management;
B. Thermodynamics and the interaction between the 2ª Law and the Economic Process;
C. Natural Resources, Environment and Society.

2. Industrial Ecology – Basic Concepts

A. Objectives of the Industrial Ecology: Natural Resource Sustainable Utilizations; Ecological and Human Welfare; Socio /environmental equity
B. Analysis of Industrial Production Systems
C. Energy and Material Flows
D. Analogies with Natural Systems: Industrial Metabolism; Open Systems versus Closed Loops

3. Industrial Ecology – Strategic Entrepreneurial Management

A. Environmental management as a support to Entrepreneur management
B. Environmental Management Systems: ISO14000; EMAS; Environmental Audit; Risk Analysis; Environmental Impact Analysis
C. *Environmental Management and its relationship with the Industry and the Market: Environmental Labels; Market of Permits and allowances to pollute; Eco-Design (Design For Environment-DFE)*

4. Methodologies and Tools of Industrial Ecology

A. Life Cycle Assessment; computational codes as a support to LCA
B. Multi-objective (environmental, economic and technologic) linear and non-linear Optimization;
C. Environmental Input/Output Tables;
D. Material Flow Analysis (MFA).

***5. Case Studies** – analysis of different production processes (automobile, electronics, food, glass, energy).*

3.1. Software Facilities

To support tutorial work and student projects, some software facilities are available, namely commercially available codes for Life Cycle Assessment (LCA), statistical analysis and linear and non-linear optimization. These commercial softwares are used at the evaluation of several case studies covering a broad range of engineering cases. As university students with access to these methodologies and commercial codes, and particularly to LCA teaching, they will bring the discussed concepts to either the workforce or graduate research, as also reported by Cooper and Fava (2001).

During each semester a set of worksheets is developed to guide the students during their practical sessions, and to create an information base to be assessed by the forthcoming classes.

At this moment, the course owns a academic license of PRé Consultant's LCA Simapro 5.0 product, a academic license of statistics analysis software SPSS and a demo license of GAMs, running at the computers laboratory of the Faculty of Technology. These codes are used to assess several types of problems during the research projects to be accomplished by the students throughout the course.

3.2. Evaluation

The students are evaluated basically through their research competence and their capacity to integrate those concepts discussed within the classes. Due to the mixed profile of the classes, the students are stimulated to group themselves keeping these multi-engineering skills within the teams.

The groups are called to analyze several mini-projects to look into those themes usually addressed at their former engineering education through the lenses of the industrial ecology concepts. These projects include several tasks, namely the analysis of the knowledge evolution by studying different scientific documents and mainly the assessment of the case studies by means of ecology industrial methodologies.

During this third version of the course, at the first semester of 2003 (March-June), an innovative evaluation system will be used. At the same period, this course will be taught at the Faculty of Engineering/University of Brasilia and at the Instituto Superior Tecnico/Technical University of Lisbon. Both teachers aim at promoting specific projects that will put together students from both sides of the Atlantic Ocean, addressing both countries relevant themes that can take advantage from this opportunity to be assessed by different cultural heritages.

3.3 Alumni Assessment

Since this discipline has been presented three times, an assessment of student's response has been made. This evaluation is performed at the end of the class period by the Under-Graduation Courses Management Department, and presents a general overview of the performance of each discipline in terms of 5 topics, namely the assessment of the syllabus, the teacher, the students individually and as a group, and of the available infrastructure within the department.

As a general form, the discipline was graded by the students between 8 and 10 (highest grade of 10) to all the evaluated requisites. Nevertheless, it is worth highlight that one of the best evaluations was the *importance of the topics analyzed during the classes for the professional development of the engineer*.

On the same way, the *brainstorming process* was highly rating, mainly due to the exchange of ideas among the several categories of engineers attending the classes.

4. Conclusions

The Department of Mechanical Engineering of the University of Brasilia has given its first steps in making available a forum of discussion of sustainable development issues, facing the fact that the orthodox engineering curricula are not anymore addressing the central issues of society, and that there must be an evolution on the way engineers are educated.

In this context, the introduction of an Industrial Ecology course in the Faculty of Technology of the University of Brasilia has been identified as a first approach to launch sustainable development discussion in all engineering curricula.

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