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An Interdisciplinary Course Based in the Thermodynamics of Irreversible Processes

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ABSTRACT

A growing demand for interdisciplinary courses was confirmed and analyzed at Universidade Estadual de Campinas (UNICAMP) by an internal survey (Tavares, and Lazzaretti Bittencourt, 1998), with the objective of identifying the nature, and extent of this need, and guide the implantation of adequate programs. Student's interests ranged from broad subjects in technological, and exact sciences, humanities, art, to non-academic subjects more related to general culture, and even to social life. It was also clear that students were interested in knowledge not directly obtained in the specific fields they were enrolled in .In this paper we discuss contents and methodology aspects of an Interdisciplinary Course originally created as a Special Topics, originated in Irreversible Thermodynamics for Engineers, later modified to expose our students to fields, and concepts traditionally considered far apart from engineering. Since the interdisciplinary courses are open to all students, we observed a growing participation, of students from Economy, Philosophy, Social Sciences, and Physics.

Keywords: Interdisciplinary, thermodynamics, irreversibility, complexity, purposiveness

1. INTRODUCTION

In paper presented at the ICHEAP-4 (Bittencourt, 1999), it was mentioned that " Real systems, of great interest to the Chemical Engineer are often open, coherent, purposive, described by non-linear dynamics, and irreversible. Irreversible thermodynamics is presented in this Paper as an element for the unification of a wide range of disciplines from engineering to biology, to economics, to sociology. This integration resulted from the enormous development of computers capacity and accessibility, and its use in the study of nonlinear dynamics system with wide applications in various areas. As pointed out (Glansdorf and Prigogine, 1971) " the idea of evolution emerged associated with two conflicting aspects: in thermodynamics " Essentially as the evolution law of continuous disorganization, i.e. of disappearance of structure, introduced by initial conditions." While " In biology or in sociology, the idea of evolution is, on the contrary, closely associated with an increase of organization giving rise to the creation of more and more complex structures. " From this point on we can take up an adequate presentation of thermodynamics, pointing out first that the vast majority of the processes in nature consists of irreversible, open, nonlinear, discontinuous systems (Katchalsky and Curran, 1974). Course presentation starts by introducing the subject of classical thermodynamics, then proceeds to linear and irreversible, to nonlinear and irreversible, in an introductory level, getting to the concept of "*nonequilibrium as a source of order",* and a kind o primitive source of coherent behavior, characteristic of the so called dissipative structures. Flexibility of content and depth in the Course, mentioned above, is needed, in function of the composition of each class, where broad differences in mathematical training is an important problem to be dealt with.

Intensity and depth in the thermodynamics, fundamental to the course structure, was also adjusted depending on the class composition. Our experience strongly indicates the need of more mathematical training, probably in the form of new approaches, utilizing plenty of visualization, in fields where the subject is generally absent in our university –humanities.

We are not aiming at the traditional mathematical knowledge as presented in regular courses, but at developing the ability of the student to understand, somehow, as an example, that the " *multiplicity of solutions in nonlinear systems corresponds to a gradual acquisition of autonomy from the environment."* later seem as an essential feature in biology, and in other purposive systems. This kind of simple phenomenon of self-organization in systems far from equilibrium is the start point for a discussion, later in the course, of the emergence of complexity in highly complex systems. As we pointed out before (Glansdorf and Prigogine, 1971), "the far from equilibrium approach... may act as an *element of unification* bringing closer problems belonging to a *wider range of disciplines*." This *element of unification* provided by irreversible nonlinear thermodynamics, a field intensively studied by Prigogine, consists in a powerful instrument for the chemical engineer who will be confronted by the increasing demand of *interdisciplinary*, cooperative study and research work. . The introduction of this Interdisciplinary Course results also from the observation of the interest *the other way around,* that is from students in biology, sociology, economy, and philosophy, for understanding the nature of purposive systems The lack of sufficient mathematics disciplines in humanities (if any at all) is one of the main problems in this interdisciplinary course. We do not have otherwise any difficulties in teaching the necessary thermodynamics to students from the humanities area.

2-Discussion

The thermodynamics part presentation, which starts the course, is conducted with the underlying goal of contrasting later in the course, a theory of '*destruction of structure"* with a "*theory of creation of structure "* (Glansdorf and Prigogine, 1971), associated with diversification and evolution toward complexity, in a hierarchy of dissipative structures which will include biological, economic, and social systems. Before we proceed, we should point out that although the concepts and subjects involved in the course are potentially highly technical, we limit ourselves to an introductory level, adequate for undergraduates, but open to graduate students, without losing the objective of giving the student a broad view of the subject.

Since we are interested in establishing basic aspects of the nature of living organisms, and organic and coherent systems in general, within the context of thermodynamics, we introduce them as " ...nonequilibrium, open systems, in which irreversible processes are occurring." We relied on the excellent workHatchalsky and Curran,1974), " Nonequilibrium Thermodynamics in Biophysics "(as a rich, quite appropriate, and innovative source, used to elaborate our class notes (especially Chapter 1 to Chapter 4). Linear irreversible thermodynamics, as a subject, is a necessary step in the direction of dealing with biological systems, considering that classical thermodynamics, as pointed out by Katchalsky (Katchalsky and Curran, 1974), describes " systems in equilibrium or undergoing reversible processes and is particularly applicable to closed systems." The bibliography of the course includes several important texts, which contributed to the theory of thermodynamics of irreversible processes, and its integration with other areas, as mentioned above.

The molecular basis of entropy is included in the thermodynamic presentation, and simple probabilistic calculations are utilized to illustrate the entropy concept - the tendency of the particles to maximize the spreading in accessible configurational, and energy levels in isolated systems.

The unidirectional increase in entropy in natural processes is given as establishing the direction of time, while systems described, as an example, by the wave equation, are invariant with respect to the transformation t to - t.

We then proceed to introduce the basic features of living beings, following very closely the first chapters of Jacques Monod " Chance and Necessity" (Monod, 1997), a seminal book for our approach in this course (Chapters I to VII). Monod discusses three interconnected elements, in simultaneous action in all living beings, which constitutes what he calls S*trange Objects* (Chapter I), understood as "*objects endowed with a purpose or project "*, *that* is: *reproductive invariance, teleonomy, and autonomous morphogenesis,* The proposed projective nature of living beings will set up the scenario for the projective nature of man, pervading his social and economic activity.

Following the presentation of the thermodynamic material which covers, in an introductory level, classical and irreversible thermodynamics, the course content based on Monod's work is presented, appearing as an "apparent contradiction", considering the tendency to the destruction of structure associated with the second law. We have observed that this approach seems to be entirely new to most students. Another subject we have used to illustrate of open, purposive, non-linear systems is Economics.

The mechanist view of Economics, the fiction of homo *oeconomicus* , leads Georgescu-Roegen to state that " No science has been criticized by its own servants as openly and constantly as economics." (Georgescu-Roegen,

1971) As he points out ' a circular flow between production and consumption with no inlets and no outlets, as the elementary textbooks depict it." adding that " … among economists of distinction " ...only Alfred Marshal intuited, that biology, no mechanics, is the true Mecca of the economist." I believe this determines the order of presentation thermodynamics, irreversibility -> biology -> economy. It also explain the choice, and order of authors and subjects.

With respect to the mathematics involved, with students that had Calculus, and a course in Differential Equations, we present the mathematics associate with the functions of state (total differentials, Pffafian equations, Carathéodory principle). " Elements of Mathematical Biology" written by Alfred J. Lotka in 1924 (Lotka, 1924), under the title of " Elements of Physical Biology", fits quite well the objective of introducing, without getting highly technical, the problem of non-linearity within the context of biology. We present the law of population growth and some cases of interspecies interaction, including the cases of conflicting populations (like predator-prey). The topographic charts of the integral curves of a two variable system is used to illustrate the evolution possibilities of this system in time leading, for example, to steady states, cyclic behavior, stable and unstable behavior. We strongly rely in visualizations and applets available at the Internet.

We discuss new mathematical concepts which appeared in the 1980s leaving academic isolation, to get not only some "public attention", but also to catch the interest of other areas. This resulted from the tremendous growth in computer capacity and accessibility. What consists, to a certain extent , in a new language is then introduced, such as in dynamical systems - bifurcations, attractors, repellers, chaos, fractals, and complexity. The logistic equation, using iterative online facilities is used to illustrate behavior in time and in the phase plane, chaotic behavior, fixed points, stable behavior, and bifurcations. A selected list of very interesting online sources very helpful for the student to visualize and understand some of the concepts above mentioned are accessible at the TELEDUC system developed in UNICAMP, open to registered students to access course material using the internet

We present the emergence of spatial-temporal order in self -organizing systems first "... as the result of nonequilibrium constraints and appropriate nonlinear coupling, characterizing regulatory processes at the molecular level. " (Nicolis and Prigogine, 1977). Pointing out that: ". The laws describing the growth, decay, and interaction of biological populations, and social systems are very closely analogous to those of chemical kinetics in general, and to those of competing biopolymers in particular. " In more complex problems- ecosystems- the processes identified by Nicolis and Prigogine, as the mechanism which may be generalized to other organic and coherent processes of assemblies of populations, such as social and economic phenomena, which are: processes of genetic origin - involving life, death and mutation. Those are phenomena involving competition intra- and inter-specific of populations – medium, with limited resources; analyzed as regulatory processes. We have attempted to present and introduce the core content of this course, which has as objective to unify concepts from classical thermodynamics and irreversible thermodynamics, with concepts pertaining to biology, such as teleonomy, autonomous, morphogenesis, and reproductive invariance, which are active in al forms of life. In "contrast" with the second law, as mentioned before, Nicolis and Prigogine point out that " In biology or in sociology, the idea of evolution is, on the contrary, closely associated with an increase of organization giving rise to the creation of more and more complex structures. "

Nonlinear behavior is also an integrand feature of the increase in complexity. Therefore, students must get a feeling for the physical implications of nonlinearity, corresponding, for instance, to an increased *autonomy from the environment.* The students add the final step in the course as they apply these concepts to problems they find of interest related to their own fields of interest and trainee programs.

3-Conclusion

We have presented, and introduced the core content of this course, which has as objective to unify concepts from classical thermodynamics and irreversible thermodynamics, with concepts pertaining to biology, such as teleonomy, autonomous morphogenesis, and reproductive invariance, which are active in al forms of life, and human activities. In "contrast" with the second law, as mentioned before, Nonlinear behavior is also an integrand feature of this increase in complexity. Therefore students must have a feeling for the physical implications of nonlinearity, corresponding, for instance, to an increased *autonomy from the environment.*

In a recent paper published at *The McKinsey Quarterly,* Stuart A. Kauffman (Kaufman, 1995) pointed out that " At a first glance, the adaptive evolution of living organisms, and the development of human artifacts seem worlds apart. When genes mutate, it does not so intentionally. The mutation may be helpful, harmful, or neutral as far as the survival of the species is concerned. By contrast human artifacts like tools, products, and even organizations are the fruits of a conscious struggle to invent and improve.

What can biology and technology have in common? Perhaps nothing, perhaps a great deal." Our question is " What can irreversible thermodynamics, biology, dynamics, economics, technology, social systems have in common?"

What we attempt to achieve with this course is to introduce, in a very modest way, the unification of knowledge that we believe necessary for the student. Some of the ideas mentioned in this paper are embedded in theories and subjects still undergoing change and evolution themselves. In the paper we presented in the last ICHEAP-4 (Bittencourt, 1999), we quoted earlier Glansdorf and Prigogine (Glansdorf and Prigogine, 1971), who pointed out hat "the far from equilibrium approach... may act as an *element of unification* bringing closer problems belonging to a *wider range of disciplines*." This *element of unification* provided by irreversible nonlinear thermodynamics and biology, consist in a powerful instrument for the student who will be confronted by the increasing demand for study and knowledge reaching beyond the walls of disciplines. We should point out that in the book "The death of economics" (Paul Ormerod, 1994), in Part II, takes the issue of the future of economics using the concept of attractors to discuss the relation between unemployment and inflation. The Lotka-Volterra equation is used in this context. Furthermore, since Georgescu-Roegen book (see reference above), the field of Evolutionary Economics, has added to the discussion about the nature of Economics and to the proposition that its roots are evolutionary (Hodgson,1993).

REFERENCES

Bittencourt, E. , Thermodynamics of Irreversible Processes of Irreversible Processes and the Teaching of Thermodynamics in Chemical Engineering- an Introductory Discussion" , ICHEAP-4, Florence, May 2-5 , 1999.

Georgescu-Roegen, N.,*The Entropy Law and the Economic Process*, Third Edition,Harvard University Press, Cambridge, Mass., 1971.

Glansdorf, P., and Prigogine, I., *Thermodynamic Theory of Structure, Stability and Fluctuations*, Second Edition, John Wiley & Sons Ltd., New York, NY, 1971.

Hodgson, G. M., "Economics and Evolution", Ann Harbor,MIT Press, 1996

Katchalsky, A., and Curran, P. F., *Nonequilibrium Thermodynamics in Biophysics*, Third Edition, Harvard University Press, Cambridge, Mass. , 1974.

Lotka**,** A. J., *Elements of Mathematical Biology*, Dover Publications, Inc., New York, NY, 1956.

Maria da Conceição Tavares e Mara F. Lazzaretti Bittencourt , Relatório Interno, " Análise das expectativas dos Alunos de Graduação da Unicamp em Relação às Disciplinas AM - Atividades Multidisciplinares" , Unicamp, Abril de 1998.

Monod Jacques, " *Chance and Necessity",* Penguin Books, London,England, 1997.

Nicolis, G. , Prigogine, I., *Self-Organization in Nonequilibrium Systems*, Wiley-Interscience, New York, 1977.

Ormerod,Paul," *A morte da economia*",Editora Schwarcz, SP, Brasil, 1994.

Stuart A. Kauffman, "Technology and evolution: Escaping the Red Queen Effect," The McKinsey Quarterly, 1995 Number 1, p. 126

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