**MAREK FRANKOWICZ**

*Faculty of Chemistry, Jagiellonian University, Krakow, Poland*
E-mail frankowi@chemia.uj.edu.pl

# INFORMATION AND COMMUNICATION TECHNOLOGY IN SCIENCE TEACHING: HOW TO PROMOTE SYSTEMIC THINKING

**Complexity**

One of the realms of modern sciences provoking much discussion and controversies is the complexity theory. A holistic approach to science (a kind of return to the 'natural philosophy' of 17th century) can be found mainly at the frontiers of 'science for scientists'. On the one hand, a quest for *Theory of Everything* (the 'Holy Grail' of modern physics) engages top minds working in cosmology, a field theory and elementary particles (Barrow, 1991; Weinberg, 1992). On the other hand, numerous theories of complexity in natural and social sciences, such as a system theory, cybernetics and synergetics emerged in the second half of 20th century (von Bertalanffy, 1975; Haken, 1978;, Gleick, 1987). One should also mention that the above mentioned theories have been anticipated by A.A Bogdanov who proposed to unify all human and natural sciences, by considering them as the systems of relationships, and by seeking the organizational principles that underlie all kind of systems. His 'opus magnum' entitled 'Tektology: Universal Organization Science', was finished by the early 1920s. The feeling that 'the world is orderly and can be explained by a small number of natural laws' (Wilson, 1998) is steadily expanding. Even if some criticism has been raised recently (Horgan, 1996), the ideas coming from complexity and chaos theories appear in philosophy and theology (Russell, 1997), sociology (Eve, 1997) and even inspire art and literature (Hoffmann, 1992).

However, there is a lack of systematic education at various levels (starting from the pre-university level up to the doctoral studies) which would promote the new ideas and show 'the art of complexity' in proper perspective. As 'Natura abhorret vacuum', at present, wider society is mainly exposed to pseudo-scientific interpretations based on the selected elements of modern science. Such notions as 'chaos', 'fractals', 'black holes' etc. are abundant in present-day SF and esoteric literature. They are also widely used (overused) by the New Age. We can also find 'gnostic fractals', 'Tao of chaos' (Walter, 1994) and many other combinations of occult and elements of complexity theories.

**"If not us, who? If not now, when?"**

It seems to be thus natural that the scientific community shall counteract such flood of nonsense. However, most of Science courses often do not include recent developments in natural sciences and the present 'classical' approach to natural phenomena, not mentioning such concepts as 'chaos', 'self-organisation', 'fractals' etc. There have been some attempts to present modern science (with elements of synergetics) in a way accessible even to the secondary school students (Krempasky, 1992; Ferreol, 1996). However, such approaches are rather exceptional even in the undergraduate university curricula. The abundant popular science literature dealing with complexity, chaos theory etc. concentrates rather on the particular aspects of the subject (e. g. fractal geometry), presents individual views of authors and in most of the cases cannot be used as teaching material.

**Teaching complexity theory at the faculty of chemistry, Jagiellonian University**

In the Jagiellonian University (Faculty of Chemistry), we are gradually introducing the elements of the 'new science' of complexity to the curriculum. The new elements are introduced at three levels:

- *Undergraduate level (3rd year):* the elements of the theory of dynamical systems, the application of chemical methodology to modelling biological and social phenomena etc.
- *Graduate level (4th year):* an elective course unit 'Self-organisation in chemical and biological systems'. The main stress in M.Sc. course is put on the chemical applications of the synergetic approach. Most of the examples concern the chemical systems (oscillatory reactions, chemical chaos, surface reactions and pattern formation etc.). The course is illustrated by extensive computer simulations and laboratory shows of the oscillating reactions.
- *Doctoral level:* We also offer an elective course unit 'Elements of Synergetics' for the doctoral students. The course for the doctoral students concentrates on showing universality of the complex phenomena. In particular, the applications of methodology originating from chemistry (kinetic equations,

reaction-diffusion processes etc.) to the other areas of science (biology, ecology, sociology etc.) are shown. For example, the chemical scheme: A + X → 2X, $X \rightarrow D$, can be also used in ecology (evolution of population of herbivores X) and epidemiology ($A$ – healthy person, $X$ – sick person). Hysteresis and phase transitions can also occur in the social systems. Kinetic equations and cellular automata have been used to model the historical processes.

A participant of each course has to prepare an 'essay' describing in a popular way an example of self-organisation in the natural or social systems. The examples of the essays may include the topics 'Dynamics of Marital Interactions: Divorce Prediction and Marriage Repair', 'Noise-Induced Transitions in Photochemical Reaction', 'Animal Coat Patterns', 'Pattern Formation on Catalytic Surfaces', 'Nyos – The Killing Lake'. The students are encouraged to present their essays during seminars, summer schools etc., promoting thus 'scientific literacy'.

**ICT in promoting complexity**

There are some simulation packages, such as PHASER, which allow for simple numerical analyses and visualisation of dynamical processes. Also numerical techniques developed for the sake of physical and chemical research (Molecular Dynamics, Monte Carlo, cellular automata) can be adapted to simulate ecological, sociological and even historical processes. Our doctoral students, who worked on the dynamics of surface catalytic reactions, adapted their software to model the problem of 'how to feed deer in an optimal way' (animals wandering through the forest in winter and looking for food have been modelled as molecules undergoing surface diffusion and arriving at active centres being energy depots) There are many other examples how seemingly complicated processes can be described and approached using modern ICT; simulations are no more realms of theoretical physicists and chemists.

Thanks to the ICT students (even those of arts and humanities) can get acquainted with important notions of modern science and even can use them in their practice; let us mention once more (Hoffmann, 1992), where chaos and order inspire artistic photography and literature.

**Final remarks**

We intend to extend our offer towards wider audience, through the lifelong learning schemes and modules for secondary schools. A basic knowledge of the theory of the complex systems results in better understanding of natural and social processes and promotes 'scientific literacy', immunising society to pseudo-scientific 'TechGnosis' (Davis, 1998).

**References**

1. Barrow, J. D. (1991). Theories of Everything. The Quest for Ultimate Explanation, Oxford University Press, New York.
2. Bogdanov, A. A. (1920). Tektologia (in Russ.). English translation: P.Dudley (1996) 'Bogdanov's Tektology', Centre for Systems Studies, Univ. of Hull UK.
3. von Bertalanffy, L. (1975). Perspectives on General System Theory, George Braziller, New York.
4. Davis, E. (1998). TechGnosis, Three Rivers Press, New York.
5. Eve, R. A., Horsfall, S., Lee, M. E. (Eds.). (1997). Chaos, Complexity, and Sociology. SAGE Publ.
6. Ferreol, R. (Ed.). (1996). Systèmes Dynamiques. Editions Archimède, Paris.
7. Fischer, E. P. (2001). Die andere Bildung, Ullstein Verlag.
8. Gleick, J. (1987). Chaos. Making a New Science. New York, NY, USA: Penguin Books.
9. Haken, H. (1978). Synergetics, Springer Verlag, Berlin.
10. Hoffmann, H.-J., Hrsg. (1992). Verknüpfungen. Chaos und Ordnung inspirieren künstliche Fotografie und Literatur. Birkhäuser, Basel.
11. Horgan, J. (1996). The End of Science. Facing the Limits of Knowledge in the Twilight of the Scientific Age. Addison-Wesley.
12. Krempasky, J. (1992). Evolucia vesmiru a prirodne vedy (Evolution of the Universe and Natural Sciences). SPN, Bratislava.
13. Paulos, J. A. (1989). Innumeracy. Mathematical Illiteracy and Its Consequences. Hill and Wang.
14. Russell, R. J., Murphy, N., Peacocke, A. R. (Eds.). (1997). Chaos and Complexity. Scientific Perspectives of Divine Action. Vatican Observatory Publications, Vatican.
15. Schwanitz, D. (1999). Bildung. Frankfurt.
16. Snow, C. P. (1993). The Two Cultures. Cambridge University Press, 1993.
17. Sokal, A., Bricmont, J. (1998). Fashionable Nonsense. New York: Picador.
18. Walter, K. (1994). Tao of Chaos. DNA & The I Ching. Unlocking the Code of the Universe. Element, Shaftesbury.
19. Weinberg, S. (1992). Dreams of a Final Theory. Wintage Books.
20. Wilson, E. O. (1998). Consilience. The Unity of Knowledge. New York: Knopf.