System Dynamics in Educational Science: An Experience of Teaching Production-Distribution Mental Models Building

Daniel Thiel
Tours School of Management
ESC, 1 rue Léo Délibes, BP 0535
37005 Tours Cedex, France
Tel: 33 47 27 42 43 Fax: 33 47 27 56 55

Abstract

We have tackled the problem of teaching business logistics. Our vision and knowledge of the industrial world and particulary its logistics are obviously not the same as that of our graduate and post-graduate students without professional experience. Therefore, our teaching difficulty consists in adopting the means of transferring knowledge to this specific public. How can system dynamics contribute to this knowledge transmission ?

The originality of this paper consists in placing our training based on system dynamics concepts and tools, in relation to different traditional pedagogical doctrines and methods (attractive, interrogative, intuitive and active methods).

We present also a particularly analysis of different methods of formalizing knowledge in production-distribution systems learning.

This study has led us to use management games even very limited ones, built by students themselves. This is the solution that we advocate in our approach to logistics using system dynamics.

System Dynamics in Educational Science: An Experience of Teaching Production-Distribution Mental Models Building

We have tackled the problem of teaching industrial logistics. Here we describe logistics in the broad sense of the word as defined by the Council of Logistics Management (CLM) : «Logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of consumption for the purpose of conforming to customer requirements». So we are interested in production and distribution system logistics.
The different types of knowledge to be acquired in the field of logistics area can include many aspects : static, kinematic and dynamic.

Fig. 1. Different visions of logistic education

	Aspects	Educational objectives
LOGISTICS ≠	STATIC ASPECT	Structural knowledge of operating systems
LOGISTICS = ↗	KINEMATIC ASPECT	Structural knowledge of driving systems
↘	DYNAMIC ASPECT	Knowledge of the flow dynamics

Within the scope of industrial systems description, we have noted the inappropriate static description of logistical flows. These operating systems like production, transportation or handling tools, are only physical supports which are uninteresting for a first apprehension of the complex dynamics of flows. For that reason, we prefer to orient our teaching programs towards the knowledge of materials and information movement, instead of towards substructures and installations which are of course necessary to carry out the operations.

That is why we retain the system dynamics approach as a way of investigating complex logistic systems. We propose a kinematic description of industrial systems which is characterized by information and driving systems and by an operating system described in two dimensions : uncertainty and complexity. The behaviour dynamics is observed by model simulations from different scenarios.

We develop in this text what system dynamics contributes to the learning of complex industrial reality.

System dynamics in educational science

Firstly, we describe the cognitive process of learning based on system dynamics principles. Then, we position this type of teaching in relation to certain educational doctrines and methods.

The cognitive process of logistics learning

In the industrial field, we often note that many management consultants who advise personal polyvalency, production flexibility, cycles reduction, total quality control, industrial investments, etc... reach today the limit of their efficiency. Many successive and partial political choices do not lead to the expected results. These consultants often base themself on their past experiences, which lead unfortunately to failure. Even if R.J. Trotter et J. Mc Connel (1980) noticed that «the previous experience took an important place in problem solving and that the people have a tendancy to search for types of solutions which were successful in the past», P. Senge describes the limit of this learning by experience. According to him, there are some cases where the observation of the consequences of each of our actions are not visible. «When the effects of an action are beyond of our field of view, it is not possible to learn by experience» (Senge 1990).

How should we prepare future managers for these complex systems ? A teaching using system dynamics is an original method which stimulates intelligence through the conceptual phase completed by practical simulation experimentations. Furthermore, Alain (1959) said that «the mind go into action in contact with experience». According to Dewey, the intelligence method, as it shows itself in several steps of experimental process, implies that we keep the trace of ideas, activities and observed consequences. «The reflection must be able to review and to totalize. Thinking is to envisage retrospectively what was doing so that we gain several significances. Here is the heart of the intellectual organization and the discipline of the mind» (Dewey 1968). The objective of a teaching by modelling that we advise, is in accordance with the phrase of E. De Bono (1976) «...teaching of thinking is not the teaching of logic but the teaching of perception».

How can we represent our industrial system knowledge ? We observe in the following figures the different ways of representing knowledge of complex systems. A first approach (fig.2) develops very qualitative aspects more or less objective and more or less formalized. The second one (fig. 3) presents the classical way according to Jay. W Forrester theory (1969 and 1984).

Fig. 2 One way to represent knowledge

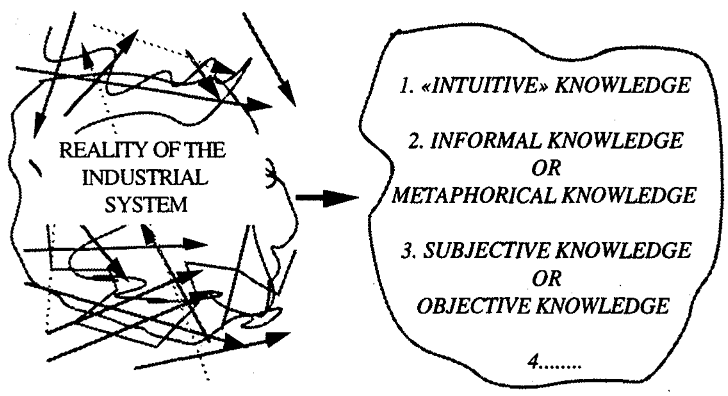
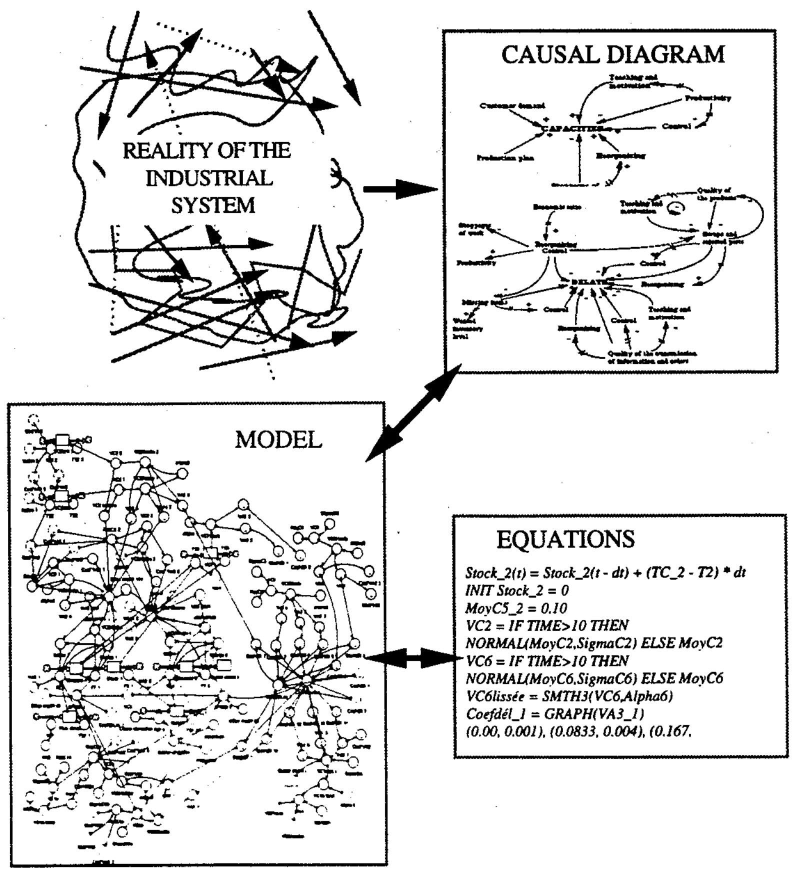


Fig. 3 An other way to represent knowledge

We shall not compare these two modes of knowledge representations because they are complementary. The first phase that we advise, consists in discovering the reality by immersion in the company in such a way to extract objectively relations between different variables through a systemic vision. This is what we call a "systemic audit" which permits us to apprehend the complex reality. The second phase enriched by the first, consists in translating these subjective, informal or intuitive[1] knowledge in a model which is progressively built from the causal relations (non-linear in most cases).

[1] H.A. Simon asserts that intuition is a recognition phenomenon (1969).



Methodologic positioning of a teaching program based on system dynamics in relation with some educational doctrines

We have chosen to present three doctrines, the first coming from the science schools and the two others, from the «new» schools. They were the most interesting to develop here and to compare with different aspects of our teaching.

The doctrine of Spencer

According to Spencer (1885), «our mind strides towards the concrete to the abstract» (in Alain's view (1959), «all conceptions must show the double mark of human order and preliminary abstraction... All mind progress from the abstract to the concrete»). We do not enter into a epistemological controverse but we try to position our educational method in relation to these two assertions. In the modelling phase, we build an abstract model from the concrete reality, but our own epistemological reference is abstract and inspire our concrete way of formalizing.

The building of causal diagram develops «the power to observe with exactitude and to think oneself» (Spencer 1885). Moreover, Spencer specifies that in the studying of sciences, «the relations that we present to the mind are causal links; and when we teach well, the students understand them like that». He also lays stress so that the student must find as often as possible, saying as little as possible. We think that teaching based on system dynamics, contributes to a spontaneous development of intellectual activities and motivation.

The doctrine of Dewey

After a critical study of the english empiricism, Dewey (1947) agrees with Rousseau and recommends the student to think as well as to handle («Learning by doing», was Rousseau's

(1762) and Froebel's (1861) expression). In system dynamics, the simulation results analysis requires us to lock back at the model structure and so, to alternate with handling and thinking.

We don't agree systematically with certain Dewey's assertions which consist in defining «the relationship, in the experience, between past works and current events», because the past can be source of judgment errors faced with complex problems.

The doctrine of Decroly

According to Decroly (1929), in educational practice, many processes are in contradiction with the classical theory of the induction and the deduction reasonings. In his opinion, the basic and visible event is that mental work at any stage, is or can be dominating, determining, or anyway influencing by different tendancies of the subject. «To indicate this special aspect of our mental activity, we propose "globalization" which is often suitable for pointing out the perceptive phase».

At the initial phase of reality perception, we try hard to develop a systemic vision which could correspond to this cognitive function of globalization.

Contribution of different education methods to the teaching based on system dynamics

Method, technique and process are sometimes difficult to distinguish, because the same expressions can cover very different realities.

As setting-up education, Cousinet (1949) thought that the word method has changed us meaning because most methods were, naturally, empirical. «They were worth what all empiricism is worth, which is only mis-managing experiences... The consumer, i.e. the student, has only the possibility to receive them».

The "didactitial "methods

The traditional "didactitial" methods are not against a system dynamics education. But we advise avoiding all preliminary acquisition of statical methods given by predefined theories. It is necessary that the student using models, discover different control mechanisms in companies, instead of learning the E.O.Q. (economic order quantity) for instance.

The attractive methods

The methods called attractive, using simulation games, have the major disadvantage of substituting the playing aspect for the real interest of the student. Alain (1969) said: «Easy attention is not attention» and Rousseau's (1762) opinion was : «among so much admirable methods to abridge the study of sciences, we should need somebody to give us a lesson demanding effort». Using management games even very limited ones, built by students themselves, is the solution that we advocate in our approach to logistics using system dynamics.

The interrogative methods

According to the UNESCO (1981), it is interesting to ask some easy questions which directly speed up the thinking system.

The interrogative methods, in particular the socratic method (Leif 1959), consider that knowledge must be conjured up in our minds which are in a latent state. These particular thought processes are present in our progressive modelling phases, which include the coupled cybernetic mechanisms of complex logistical systems.

The intuitive methods

The intuitive methods provide direct knowledge by observation, without intermediate intellectual operation. According to Piaget (1970), «the intuition remains phenomenist because it imitates the reality outlines without correcting them, and remains egocentric because it is continuously centred in the action of the moment : in a way, it misses the equilibrium between the assimilation of things based on thinking schemas, and the adaptation of them to the reality». That is the reason why this method is not appropriate for studying the flow dynamics of companies. Nevertheless, we agree with Comenius who claimed that «we look not only to know, but to understand, going back to the causes». This is the phase of building the causal diagram. Spencer's (1885) opinion is that this type of education, is only the rational organization of empirical knowledges by application of observation methods and induction rules.

The active methods

According to Piaget (1970), the active methods consider that the actual experience must be deep and elaborated by a lively thinking which will improve it. Dewey (1947) proposes that «the sharp mind must obtain the qualities which will later remain in the thought process by :
1) the habit of reflection, interest, attention, precaution,
2) the power to establish relationships between objects, near or distant, present, past or future,
3) the habit to quickly distinguish the essential from the unessential,
4) the concern to return to the causes and to go down to the effects,
5) the need to check which is the mark of the highest stage of intellectuality».

In Mialaret's (1983) opinion, «the action and the thinking are linked». In taking action, we furthered the development and the exercise of thinking; firm and solid thought manages better the action and gives it more effectiveness. The active methods have as essential objective, to produce this reaction of the personality and to strengthen the mental activity by real and original exercice. The teaching based on system dynamics contributes to develop this double relationship between reflection (through the modelling phase) and action (through the simulations).

The method of Cousinet

The art of research is the most important part of what Cousinet's (1949) method developed. In his opinion, it is much more important to see what the studentsare really doing, than to try searching what they know, because doing is much more interesting and more in accordance with their nature. System dynamics as a teaching tool for a new subject, is appropriate for this knowledge transfer by action.

The learning by simulation games

«Exceeding the training objective and approaching experimentation», was A. Kaufmann's (1976) opinion about games. According to E. de Bono (1976), «Games have an internal logic and a good player quickly learn this internal logic because it is repeated so often. Life, unfortunately, has not such internal logic...». Cousinet's (1949) thought that many games played by pleasure, do not further ones knowledge because these two notions, pleasure and progress, are both amphibologic. Nevertheless, it is possible to be not particularly interested in things which can give pleasure, and in case we are not interesting about an activity, we can meet forms which do not give pleasure but we are conscious of its necessity in the objective that we want to reach.

J. W. Forrester (1969) said about games that «there are some close similarities between the business game and the full dynamic model. A few of decisions are made by the human participants as the game progresses. In both there is a mathematical model, usually there is a computer, both concentrate on the business system, and both aspire to enhance understanding of the broader business scope. Here the similarities end».

Games builded by system dynamics models which allow an analyzing of the causes, are more efficient to understand complex phenomena (see Machuca 1992 and 1993 for example).

Conclusion

«To succeed in a linear approach gives satisfaction; to succeed in a non-linear, holistic, heuristic, approach brings pleasure in discovering a significance which concern ourself» (L.V. Williams 1986).

B. Richmond (1986) considers that evolutionary fusing of three threads : educational process, thinking paradigm and learning tools, can successfully create a permanent change in the way people learn.

An experience of teaching production-distribution mental models building

Our current knowledge of logistical systems are often empirical. We identified two essential types of working :

- the first one, which we call "procedural", is based on a formal reasoning and on deterministic bases,
- the second one, called "expert", is based on usual job rules acquired by «organizational learning».

In reality, many decisions «easy» to make[2], are essential to the real time control of the industrial activity. In the short term, we observed companies, with objective of improving their "reactics", quickly overcome simple problems or even, simplified problems by reduction of complexity level. Meanwhile, in a globally, really complex problems are not solved. For instance, in some companies, how can we explain (and try to improve) a too high level of inventories, apparently necessary to garantee a satisfactory customer service ? The responsabilities of such an anomaly, are varied and can be imputed just as easily to the production tool with little flexibility and a lot of hazards, as to the bad quality of information and order transmission. We direct our teaching programs towards essential mechanisms implementation to overcome such dysfunctions.

Our approach also consists in trying to bring together the multiple cinematic structures identified by students with the dynamics of some industrial behaviours, independently of the physical activities of different companies. Therefore, it is not an analysis of a particular logistical system, but a research of relationships between different industrial structures and typical primitive behaviours.

The numeric results only have a relative value for comparison between different elaborated models[3].

Problematics of teaching

Industrial systems described in term of feedback structures, are in general too complex to be treated by mathematics and their dynamic behaviours can only be represented by non-linear models.

According to D. Freedman (1993), «the managers expect to understand what relations between cause and effect inside their organizations are, whereas in reality the links between action and its result are more complex than could be imagined». P. Senge call this the «dilemma of the content assimilation».

---

[2] programmable decisions in sense of H.A. Simon (1960).

[3] according to J.W. Forrester (1969) : «a high precision of results is secondary to improve knowledge».

An efficient, objective and relevant method should consist in observing in real time on the shopfloor, the decisions taken in the systems and in analysing the consequences. J-C. Moisdon (1984) also said, «it is only possible to analyze the working of organization when it begins, and what is more a force field reveals its structure when it is possible to observe immersed objects». But the delay of this approach is too long and explains the ordinary use of computer simulation. One of the major problems of simulation model building is its validation. In this way, it is advised a priori to inspire existing theories for building a model which can be completed or adjusted by a ground observation (according to B. Walliser (1977) who considers that it is a circular process which can start at any phase). This behaviour investigation method currently presents deficiency because no laws exist to describe particular problems frequently present in industries, for instance : reducing production cycles in case of decreasing the productivity, reorganizing production and increasing capacity to a step in the demand, etc. Only general theories like system theory or some decision theories, can help us to modelize industrial complex systems.

We advise the system dynamics approach to apprehend logistics, starting from elementary knowledge conceptualization and progressive building of models. «System thinking» according to P. Senge's demonstration (1990), implies having the ability to understand what are the key relationships which influence the behaviours present in complex systems when it is necessary to «take these sets into consideration».

Refering to our previous figures, the figure 2 corresponds to a knowledge representation mode that we call "expert" and the figure 3, a procedural mode corresponding to the logical model building phase.

Organizing of industrial systems modelling teaching

As specified by A. Bensoussan (1982), «the first objective of modelling is positivist in the sense that it develops knowledge models. The second aspect is more normative and can help the practitioner to «objectivize» the pictures that he perceives as subjective».

A descriptive choice of industrial systems

The industrial systems are generally described by technical, economical and social aspects[4]. Indeed, the driving decisions emerge from an industrial organization constituted by people and technologies[5]. In relation to the problematics of industrial logistics which consists in assuming a permanent activity control, the descriptive model based on complexity and uncertainty of environment[6], seems to be the most suitable.

Pedagogic practice of modelling

We developed a teaching approach based on progressive system modelling[7].

Firstly, we ask our students either to build limited models to understand different mechanisms in materials management for example (types of models presented by J. Lyneis (1988) in «Corporate Planning and Policy Design : A System Dynamics Approach»).

4 J. Woodward was particularly interested in sociology as an explicative tool of organizational phenomena (1971).
5 according to P. Baranger, it seems necessary to establish a relation between complexity and technology (1992).
6 this typology of industrial systems is proposed by J-P. Kieffer and Y. Gousty, (1986 and 1988).
7 this educational process and the combining tools were using in a second cycle teaching progam (industrial logistics curse) and two postgraduate programs (in production management and logistic business curses. In the last one, the concerned public have generalist engineering or management backgrounds with solid bases in statistics and mathematics (see Thiel 1992 and 1993a).

Then, they work on more complex generic models[8] and observe "in vitro" anti-intuitive behaviours. In this second phase, the educational objective of simulations consists in improving the understanding of complex behaviours and in guiding the driving of these systems. The system dynamics is activated by fluctuations of the most sensitive variables[9].

This active method (according to Piaget, 1970) allows us to apply the simulation results to the companies and gives us the possibility to modify industrial system driving. It also permits us to improve the performances of the essential regulation loops in uncertainty.

Conclusion

This teaching implies a global vision of industrial management . It is composed of a base of theoritical system analysis and modelling applications. Systemic «audits» of industrial units contribute to the global perception of these complex feedback systems.

Therefore, we accentuate essentially the necessary effort to a logistic management learning by systemic modelling teaching. This approach introduces a larger and multidisciplinary vision of industrial systems and vision of its dynamics to management.

References

Alain. 1959. *Propos sur l'Education*. Paris: Presses Universitaires de France.

Baranger, P. 1992. Gestion de la production; un état de la littérature récente. *XIèmes journées nationales des IAE, Annales du management.* : 73-86.

Bensoussan, A. 1982. La recherche en gestion. *Colloque FNEGE Nancy.* : 5-29.

De Bono. 1976. E. *Teaching Thinking*. Penguin Books.

Cousinet, R. 1949. *Une méthode de travail libre par groupes*. Paris : Les Editions du Cerf.

Decroly, O. 1929. *La fonction de globalisation et l'enseignement.* Bruxelles : Maurice Lamertin.

Dewey, J. 1968. *Expérience et éducation.* Paris : Librairie Armand Colin. traduction of Dewey. J. 1947. *Experience and Education*. Ohio : Edition Kappe Delat Pi. Heidelberg College.

Forrester, J. W. 1969. *Industrial Dynamics*. Cambridge; Massachusetts : MIT Press : 344-361.

———. 1984. *Principes des systèmes.* Presses Universitaires de Lyon.

Freedman, D. 1993. A «nouvelle» science, «nouveau» management. *Harvard-l'Expansion*. printemps : 6-13.

Froebel, F. 1861. *L'Education de l'Homme*. Paris : L. Hachette et Cie et Bruxelles. Ferdinand Claass.

Gousty, Y. and J.P. Kieffer. 1988. Une nouvelle typologie pour les systèmes industriels de production. *Revue Française de Gestion*. Juin-Juillet-Août : 104-112.

Kaufmann, A., R. Faure and A. Le Garff. 1976. *Les jeux d'entreprises.* Paris : Presses Universitaires de France. Que sais-je ? : 71.

Kieffer, J.P. 1986. *Les systèmes de production, leur conception et leur exploitation.* Thèse d'Etat. Université Aix-Marseille III : 40-48.

Leif, J. and G. Rustin. 1959. *Pédagogie générale par l'étude des doctrines pédagogiques*, Paris : Librairie Delagrave.

Lyneis, J.M. 1988. *Corporate Planning and Policy Design : A System Dynamics Approach.* Cambridge: Pugh-Roberts Associates. 3.

Machuca, J.A.D. 1992. The need for a new generation of Business Games for Management Education. *System Dynamics Review*. : 22-1.

Machuca, J.A.D., M.A.D. Machuca, A. Ruiz and J.C. Ruiz. 1993. Systems thincking learning for management education and transparent box business games. What are our ideas and how are we going abour it in Sevilla ? *Second European Congress of Systems Science*. Praha, Czech Republic.

8 these models are described in Thiel (1993b and 1992c).

9 these indicators were picked in our previous survey (see Thiel 1993b).

Mialaret, G. 1983. *Introduction à la pédagogie*. Paris : Presses universitaires de France - 6 : 124-134.

Moisdon, J-C. 1984. Recherche en gestion et intervention. *Revue Française de Gestion*. sept-oct. : 61-73.

Piaget, J. 1970. Introduction à l'epistémologie génétique, english version. *Genetic Epistemology*. New York : Columbia University Press.

Richmond, B. 1993. System thinking : critical thinking skills fo the 1990s and beyond. *System Dynamic 9* : 113-133.

Rousseau, J-J. 1762. *L'Emile*. livre 3 : 198.

Senge, P. 1990. *The fifth discipline: the art and practice of the learning organization*. New York : Doubleday.

Simon, H.A. 1960. *The new science of management decisions*. Evanston. Harper and Row, New York. Publishers.

———. 1969. *The Siences of the Artificial*. Cambridge : MIT Press : 91.

Spencer, H. 1885. *De l'éducation intellectuelle, morale et physique*. Félix Alcan Editeur : 48-64.

Thiel, D. 1992. Formation systémique à la modélisation des systèmes de production. *in Actes du premier Colloque Européen "Productique et Formation". PRO FORMAT-92*: Marseille : 191-195.

———. 1993a. Enseignement systémique et complémentarité des modèles stochastique et continu de systèmes de production. in *Actes du Congrès AFCET'93 Systémique et Cognition. Colloque "Communication, information et esprit d'entreprise.* Paris : Afcet : 51-59.

———. 1993b. *Management industriel, une approche par la simulation.*Paris : Economica.

———. 1993c. Modèles génériques de comportement des systèmes de production. *Revue Internationale de Systémique. Afcet.* Dunod. 7 (2) : 117-142.

Trotter, R.J. and J. Mc Connel. 1980. *Psychologie, science de l'homme*. Montréal : Les Editions HRW Ltée.: 185-221. traduction of 1978. *Psychology, The Human Science*. Holt, Rinehart and Wintson.

UNESCO. 1981. *L'Educateur et l'approche systémique. Manuel pour améliorer la pratique de l'éducation*. Paris : Organisation des Nations Unies pour l'éducation, la science et la culture.

Walliser, B. 1977. *Systèmes et modèles. Introduction critique à l'analyse des systèmes*. Paris : Editions du Seuil.

Williams, L. V. 1986. *Deux cerveaux pour apprendre*. Paris : Les Editions Organisation. traduction of *Teaching for the two-sided mind*. Prentice Hall.

Woodward, J. 1971. *The structure of Organisations*. PUGH, Pugh : 56-71. Excerpt from J. Woodward, J. 1958. *Management and Technology*. H M S O : 4-21.