System Dynamics, Mental Models, and the Development of Management Intuition

Peter M. Senge
Massachusetts Institute of Technology

I INTRODUCTION

The development of management intuition should be a primary objective in using system dynamics. All too often, practitioners of such methodologies see their job as building computer models. Yet, few, if any, important policy changes will ever be based on computer models. Computer models only have an impact when they succeed in altering the basic understandings and instincts of policy makers. The role of models and modeling is not to replace but to refine intuition and judgement. Modeling can aid enormously in synthesizing the lessons of experience, not in supplanting experience. Model-builders intent on affecting change must see themselves as educators engaged in the on-going task of improving the "mental models" of policy makers and the public. Ultimately, their task is to develop the capacity within people to examine and bring their own mental models into deeper harmony with reality.

Given that the profession is inevitably involved in altering mental models, it is surprising how little attention has been given to how such models arise. How do people form and evolve their understandings and instincts regarding systems? The systems modeling field has no theory of cognitive development, and, as near as I can discern, has never even made a serious effort in that direction. Yet, it is obvious that human beings have considerable capacity to master highly complex tasks under favorable learning conditions. We drive automobiles, ride bicycles, play Mozart, and, in a few cases, even successfully manage complex systems. If they are to be effective, efforts to utilize systems models to advance management intuition must be rooted in an understanding of the mind's capacity to deal with complexity.

This short paper is intended to stimulate thinking and hopefully more serious efforts toward understanding how systems thinking tools can most effectively catalyze the development of management intuition. This effort draws from an on-going research program, the program in Systems Thinking and the New Management Style, aimed at advancing systems thinking as a practical tool for developing a more wholistic, long-term, and creative (as opposed to reactive) orientation in organizational leadership. The program involves a network of organizations, many of which have been pioneers in developing more visionary nonauthoritarian work environments. The organizations serve as laboratories to explore innovations in management education. The central premise in these explorations is that the localization of management responsibility will require transforming an organization's capacity to learn, so that local control and understanding can advance together. The research at M.I.T. is focused on developing a library of "generic structures," relatively simple models of organizational dynamics that recur in diverse settings, which can provide a foundation for that education. This paper discusses basic assumptions about learning that underlie the program.

II. LEARNING AND ACTION

One of the most persistent findings of cognitive psychology is that much apparent learning results in no significant change in behavior. The failure of education to produce enduring change is especially troubling when the primary objective of management education is improved policies. It is becoming apparent that the failure of much traditional learning relates to its limited access to the multiple dimensions of learning. This is equally true for children and adults. Educational environments that fail to engage people physically and emotionally as well as intellectually are generally less impactful than those that do. Learning that does not relate to an individual's personal objectives and personally recognized needs has less probability of being retained than learning that is perceived as relevant. Formative understandings that are not applied to daily decisions are less likely to be assimilated than those that are applied.

The first mistake of modelers and analysts intent upon teaching new understandings to managers is to assume that learning is purely a rational process aimed at conceptual understanding. The rational conceptual approach not only underestimates the role of doing and feeling in learning, it also overlooks the importance of "subconscious" processes in assimilating new understandings and developing new instincts. It is now widely recognized that the greater portion of our total mental activity goes on beyond our conscious awareness (Harman 1981). In particular, subconscious processes appear to play a major role in the linkage of learning and behavior. The subconscious is also critical in dealing with complexity because the conscious mind has very limited information-processing capacity.*

To begin to grasp the interplay of conscious and subconscious processes in learning and in dealing with complexity, consider how we have learned the many highly complex tasks we take for granted, like playing tennis, typing a letter, or driving an automobile. We go through a process not unlike what someone goes through to become a concert pianist. Very few people start off playing Mozart. Maybe Mozart didn't even start out playing Mozart. You start out playing something simple, like scales. Initially, playing simple scales is a very difficult process that demands virtually all of your conscious awareness. But it doesn't demand that for very long; it soon becomes automatic and you move on to more complicated scales. Then these demand all of your conscious awareness, until they become automatic, and you move on to simple pieces.

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* The simple division of mental activities into subconscious and conscious is not meant as a rigorous model of brain functioning but as a useful conceptual framework for understanding what happens when people master complex skills. The "subconscious" described here bears some similarity to the "reptilian brain" of the modern "triune model" of brain evolution. The reptilian brain is thought to be essential in coordinating bodily functions, habit formation, and related "automatic" mental activities (MacLean 1971, 1978).

At each level, you start off with a degree of complexity just within the bounds of your conscious ability--within the bounds of your normal awareness--to grasp. As it is mastered, this level of complexity is "turned over" to the subconscious, thereby freeing conscious awareness to focus on the next increment of learning. In this way conscious and subconscious processes cooperate in learning. Even though normal awareness is only able to handle a limited degree of complexity, we find that somehow people do learn to deal with incredibly complex tasks--such as a composition by Mozart. But, even a great pianist will often begin playing a new piece at a slow tempo. Gradually he or she picks up the tempo as he "grasps" the piece as a whole. When the time to perform the piece comes, the pianist no longer requires any "self-conscious," waking awareness to concentrate on where his or her fingers go. This frees the pianist to focus purely on the aesthetic.

That process seems to be analogous to how we deal with complexity more generally. Recall how when initally learning how to drive a standard transmission automobile, all of one's conscious awareness is occupied with learning to shift gears. Yet, eventually the tasks become automatic, and we navigate complex traffic patterns, steering, braking, and shifting gears simultaneously--and almost all of our conscious attention is on a conversation we are having with a passenger! Clearly, there are parts of our mind that deal with complexity much more effectively than our normal awareness.

Moreover, subconscious assimilation is directly linked to behavior. While conscious thoughts may dictate actions they do not necessarily result in action. Thinking about playing Mozart does not produce music. By contrast, all learned behaviors involve the subconscious. Instincts, habits, and other "automatic" behaviors are all "subconscious". Moreover, if we carefully analyze the requirements of even seemingly simple tasks, like touching the top of your head, we see that, at the physiological level, these are enormously complex and must be coordinated by an aspect of mind with much greater information-processing skills than our normal conscious awareness.

To summarize, it is essential to consider different dimensions or aspects of mind in understanding how people learn complex skills. First, the limited information-processing capability of our normal waking awareness means that complex tasks can at best be understood only heuristically or through simple rules of thumb. An interplay of conscious and subconscious processes are at work whenever people master complex tasks. Through successive iteration, progressively more complex understandings are subsumed in the subconscious, allowing conscious awareness to focus on the next increment of learning. Subconscious assimilation of new understandings is essential for the "deep learning" that influences action. New understandings grasped only rationally by the conscious mind generally fail to alter behavior because most behavior is controlled by skills, instincts, and habits beyond the immediate reach of such understandings. "Learning how to do something new" differs fundamentally from mere conceptual understanding.

III. GENERIC STRUCTURES AND MANAGEMENT PRINCIPLES

Understanding how the mind deals with complexity has important implications for how we attempt to use system dynamics to influence thinking and behavior. Somehow, our task is to replicate the interplay of conscious and subconscious that underlies all true learning. I believe that models of generic structures can play a key role in this process.

Most attempts to apply system dynamics to influence corporate and public policy violate the developmental nature of true learning. Consultants (whether internal or external to an organization) build models that are much too complex for managers to grasp. The "client" listens politely to the consultant's presentation and often feels genuinely that he or she "understands" the message. But such a process is unlikely to result in deep learning. Even when the consultant's recommendations are followed, the depth of understanding behind new actions is usually shallow. Typically, a model's recommendations are "implemented" because they "make sense" to a policy maker--that is, agree with his or her prior mental model. If the recommendations fail to agree with the mental model they usually are ignored. In those relatively rare instances where understanding and action appear to be altered, there is still a tendency to drift back to old policies because not enough of the people involved in carrying out new policies have been part of the learning process.

There are many reasons why most systems studies fail to result in true learning and change. The required process is time consuming. Few consultants are prepared or inclined to carry out the ongoing task of educating substantial numbers of managers. Many consultants are model builders, not teachers. Very few are expert in organizational change. But, most fundamentally, the models do not lend themselves to the learning capabilities of managers. The models are like starting by trying to play Mozart, rather than scales. Faced with a task he or she cannot master, most managers settle for learning to appreciate rather than play the music. And that is not good enough to ensure lasting change.

The New Management Style Program is exploring ways in which generic structures can improve the transfer of systems thinking into organizations. "Generic structures" are relatively simple models of dynamic processes that recur in diverse settings and that embody important management principles. Through a carefully structured series of exercises with progressively more complex generic structures, I believe that important insights into organizational dynamics can be assimilated.

For example, consider a series of generic structures dealing with the interaction of market growth and capacity expansion that begins with a simple "two-loop" model that represents market growth in the presence of fixed capacity.* The model is simple enough for a manager to grasp in a half-hour or less of effective interaction in a classroom or with a personal computer. The basic principle underlying this first structure is

* This series of generic structures derives from the model first presented in Forrester (1968) (see Senge 1985).

that no firm can sell what it doesn't produce. Failure to expand capacity to meet demand will limit growth through declining availability, lower product- or service quality, rising price, or a combination of the above.

Adding variable production capacity provides the next stage of complexity. Now, the dynamics become more subtle. A new management principle emerges: imbalances between market growth and capacity expansion result in fluctuations in demand and sales. Helping managers to truly understand the internal causes of cyclic behavior is often one of the most elusive tasks of a systems thinking educator. Most managers have deep beliefs that cycles in demand are externally caused--either arising from their industry as a whole or from the larger economic system. This belief lies in the lower strata of their mental models. Even when they appear to intellectually grasp the possibility of cycles arising from the internal dynamics of the firm, their emotions and world view are often deeply committed to a contrary assumption. Our experience is that looking at the output of a computer model rarely penetrates this layer of mental conditioning. For several years, we have resorted to a management simulation game that leads people, through a role-playing exercise, to demonstrate for themselves that firms can self-generate cycles. But, even the game experience is inadequate, for it will not, in itself, lead to understanding of how the cycles are generated. It will challenge the assumption of external causation, but it will not begin to build the foundation of a new mental model more consistent with reality.

I cannot honestly say that I know what is necessary to facilitate a manager in reliably reconstructing his or her mental models of the causes of cycles in a business. I believe that the role playing experience must be coupled with a chance to build one's own explicit computer models of the system structure. Probably, people will need to interract with those models until improved instincts and skills are demonstrated through superior play of the game, under a variety of test conditions. Even then, the ability to transfer these learnings back to real life will depend on how well the laboratory system matches the real system.

This again is where the generic structures come into play. The generic dynamics of interacting market- and capacity expansion provide a foundation for constructing well formulated specific models of market- and capacity expansion. Once the simpler generic model is mastered, the manager progresses to the more complex "specific model" that embodies familiar idiosyncracies of their own organization and industry.

For example, one of the participating organizations in the New Management Style Program has translated the generic market- and capacity expansion model into terms specific to the insurance industry. In addition to adopting appropriate terminology, modifications were made in the computation of profits. In the insurance industry, one consequence of marketing efforts that outstrip capacity is an erosion in the quality of underwriting, as a limited underwriting staff (which cannot be expanded rapidly due to delays in training) attempts to deal with a growing backlog of policies to be written. Reducing time to write policies boosts revenues in the short run, but results in increased losses in the long run. The overall result is to increase the amplitude of profit cycles arising from marketing-capacity imbalances, which is consistent with the large profit

cycles which have characterized the insurance industry in the past 15 years.

The important point, from an educational standpoint, is that the "specific structure" based on the generic structure be introduced to the manager only after the generic structure has been mastered. Just as the "generic" scales precede the greater challenge of a specific piece for the budding pianist, first mastering the principles of the generic market- and capacity expansion structure make it much easier to grasp the relevance of these principles in one's own setting. Obviously, this requires some patience on the part of managers eager to press on to understanding their own issues. But, our experience to date suggests that this patience will be forthcoming once people have some appreciation for the ultimate benefits of the generic approach.

This series of generic structures dealing with market- and capacity expansion includes a variety of further structures encompassing additional management principles. This includes the "bias toward underpricing," which arises when firm attempt to set price based upon estimating their "demand curve," the direct effect of price on demand. If additional competitive variables, such as product availability and product- or service quality, modulate demand based upon the adequacy of production capacity, then the demand curve will invariably overestimate the depressive effects of increasing prices. An optimal price level, from the standpoint of return on investment and average growth rate, will almost always be considerably higher than suggested by analyzing the effects of price alone on demand. Another extension of the basic structure reveals the principle of eroding goals. This structure shows how gradual erosion of goals for availability or quality of products or services can undermine incentives to expand capacity aggressively. The result can be stagnation in the face of unlimited potential demand, caused by a set of reinforcing signals within the organization that demand has saturated. Yet a third extension deals with counterproductive attempts to dampen cycles in profitability. This principle suggests that attempting to stabilize profit fluctuations (often motivated by concerns of shareholder unrest and declining stock values) can destabilize operations and actually lead to even more severe profit fluctuations.

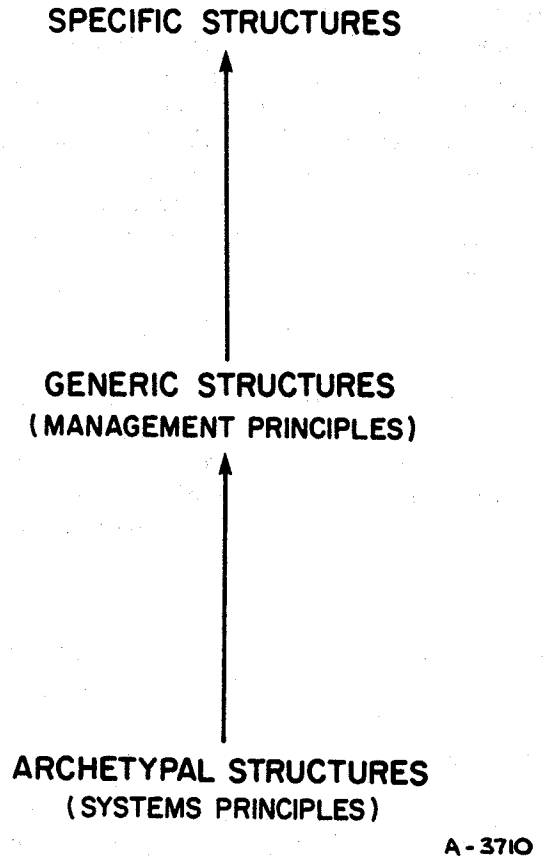
The series of generic structures dealing with market- and capacity expansion is unusually rich because these dynamics operate in the growth of any enterprise. Generic structure research in the New Management Style Program is advancing along a variety of fronts in addition to market- and capacity expansion structures. The research includes generic structures dealing with market development, technology management, human resource development, and a variety of organization development dynamics including the causes of proliferating hierarchy and organizational learning. The guiding vision for this research is to create a continually expanding library of generic structures encompassing the most important management principles of organizational growth and vitality. This library of generic structures will have two primary uses. The first is management education, involving self-paced personal computer learning modules, simulation games, and interactive video in a "management learning laboratory of the future." The second use is in developing the specific models that serve the needs of particular organizations in further management education and policy design.

IV. ARCHETYPAL STRUCTURES AND SYSTEMS PRINCIPLES

Underlying generic structures are "archetypal structures," the mathematical building blocks of all systems. It is important to distinguish these mathematical abstractions--positive and negative feedback loops, coupled positive-negative and negative-negative loop structures, "aging chains," and so on--from the generic structures that underlie particular types of processes like capital expansion, market growth, or urban stagnation.

Distinguishing archetypal from generic structures clarifies the natural hierarchy of structure in system dynamics (Figure 1). Effective education focuses on all three levels of structure: specific, generic, and archetypal.

Figure 1: A Hierarchy of Structure



The role of generic structures as interactive learning tools and as bases for specific models is now relatively clear. What is less clear, are the possible long-term effects of assimilating the archetypal structures underlying the generic structures. Numerous psychologists, starting with Jung, have stressed the role of archetypes in how we perceive reality. Archetypes often supply the building blocks and organizing principles for our mental models. For example, archetypal personalities, like the eccentric inventor or the aggressive salesmen, lead us to subconsciously categorize unique individual personalities, with the consequence that we often act more appropriately to the archetype than to the person him- or herself. Might archetypal structures lead, in a similar fashion, to new perceptions and actions?

Archetypal structures lead to systems principles, just as generic structures lead to management principles. For example, "compensating feedback" (Forrester 1969), the tendency of systems to compensate for external interventions, arises from the basic negative feedback loop that compensates for changes in any individual variable. "Shifting the burden to the intervenor" (Forrester 1969, Meadows 1982) arises from the coupling of two negative loops trying to control the same condition where, over time, one loop comes to dominate the other.* Addiction is closely related to this dynamic. Once a systems principle like compensating feedback or "shifting the burden" is internalized, it can have a profound impact on perceived reality and action. Understanding compensating feedback can lead to questioning any system intervention aimed at ameliorating a problem symptom. Shifting the burden to the intervenor suggests that any intervention may result in a reinforcing spiral of dependency and need for further intervention. The power of archetypal structures lies in their universality. There is evidence that the subconscious mind organizes information in terms of archetypal structures. Consequently, an education process designed to lead to the assimilation of a series of archetypal structures has the potential to influence the very organizing principles of our mental models.

It may well be that much of what we call "management intuition" stems from this process of assimilating generic and archetypal structures. Undoubtedly one of the most basic characteristics of the great manager is the capacity to transfer insight and judgement from one business or organizational setting to a radically different setting. This is powerful evidence for the existence of generic structures. If each situation were unique, there would be no transferability of management judgement. But the transferability of management judgement and intuition may also stem from a basic way of perceiving the world and influencing change--designing structure rather than attempting to manipulate behavior, working with underlying forces rather than reacting to events, focusing on leverage points rather than problem symptoms. The great manager is a "systems thinker" in the sense of having assimilated systems principles and archetypal structures. The great promise of effective education in systems thinking is to establish a conceptual framework and set of tools to accelerate and make more manageable the process of developing management intuition and judgement.

*See Senge (1985) for managerial examples of these principles.

V. CONCLUSION

The purpose of this paper has been to stimulate thinking about the learning process we hope to evoke in applying system dynamics to pressing organizational and societal problems. Designing this learning process requires a theory of cognitive development currently absent from the field. Such a theory must be rooted in an understanding of how the mind deals with complexity.

In this paper I have suggested that both rational conscious processes and subconscious processes must be recognized. The subconscious, in particular, appears to be critical in assimilating complex learnings and in mediating between learning and behavior. The task of systems educators is to train the subconscious mind as well as enlighten the conscious mind.

Research in conceptualizing and utilizing "generic structures" may significantly advance the art of teaching systems thinking. These models are simple enough to be understood by managers yet reveal subtle dynamics. They can create the foundation for a participative education process leading to the discovery and assimilation of basic management principles. They also serve as the starting point for efficiently constructing models representing the specific characteristics of particular organizations and industries. In the Systems Thinking and New Management Program we are discovering that it is far easier to train individuals in organizations to understand generic structures and coach them in constructing their own specific models based on generic structures than to teach them the skills to build good system dynamics models from scratch.

There is much to be done in extending the ideas and processes described here. The discussion of how different aspects of the mind interact in learning is impressionistic and needs to be more rigorously related to emerging understanding of cognition and consciousness. The discussion completely neglects other aspects of the mind dealing with personal purpose and awareness beyond direct sensory input. I have focused on the role of the more or less "automatic" subsconscious mind in developing intuition. Other researchers have defined intuition as a "natural" or direct knowing that goes beyond knowledge based on experience (Harman and Rheingold 1984). Integrating these two notions of intuition would lead to a richer picture of awareness and learning, and deeper understanding of the processes whereby mental models are formed.

I believe the most fruitful strategy for developing better theories of learning will focus on the practical challenges of translating theory into effective learning environments. In a recent article on the history of scenario planning at Royal Dutch Shell, Pierre Wack, former Planning Director, suggested that the real purpose of effective corporate planning is not to make plans but to change the "microcosm," the model of the world that decision makers carry in their heads:

> I cannot overemphasize this point: unless the microcosm--individual or corporate--is changed, no change in behavior will occur; the internal compass must be recalibrated.

> From this realization onward, we no longer saw our [planning] task as producing a documented view of the future business environment five or ten years ahead. Our real target was the microcosms of our decision makers: unless we influenced the mental image, the picture of reality of critical decision makers, our scenarios would be like water on a stone. This was different and much, much more than producing a relevant scenario package. (Wack 1985)

Wack proceeds to describe a 10-year process of learning how to use scenarios as a tool for evolving mental models. A similar challenge now confronts system dynamicists. There is very much to learn in how to create a truly realistic, stimulating, and impactful environment for ongoing learning that instills systems thinking in open-minded managers. Seriously engaging in this task could have a significant impact on the growth of the system dynamics field.

REFERENCES

Forrester, Jay W. "Market Growth as Influenced by Capital Investment," Industrial Management Review, Volume 9, Number 2, 1968, pp. 83-105.

Forrester, Jay W. Urban Dynamics. Cambridge: MIT Press, 1969.

Harman, W. "Rationale for Good Choosing," Journal of Humanistic Psychology, Volume 21, 1981, pp. 5-12.

Harman, W. and H. Rheingold. Higher Creativity. Los Angeles: Jeremy Tarcher, 1984.

MacLean, Paul D. "A Triune Concept of the Brain," Hinks Memorial Lectures, 1971, pp. 6-66.

MacLean, Paul D. "A Mind of Three Minds: Educating the Triune Brain," Education and the Brain (77th Yearbook of the National Society for the Study of Education), 1978.

Meadows, Donella L. "Whole Earth Models and Systems," CoEvolution Quarterly, Number 34, Summer 1982, pp. 98-108.

Senge, Peter M. "Systems Principles for Leadership," System Dynamics Working Paper D-3748, System Dynamics Group, Bldg. E40-294, Massachusetts Institute of Technology, Cambridge, MA 02139.

Wack, Pierre, "Scenarios: Disciplined Decision Making," Harvard Business Review, Volume 63, Number 4, September-October 1985.

Wack, Pierre, "Scenarios: Shooting the Rapids," Harvard Business Review, Volume 63, Number 5, November-December 1985.