The implications of systems thought for the design of curricula are examined. System Theory, which seeks an understanding of living systems, is distinguished from Systems Technology, the function of which is the design of contrived systems. It is argued that the system principles of unity and coherence, and of the centrality of purpose in open systems, can be readily applied to the design and illumination of curriculum. The cybernetic principles of feedback and requisite variety suggest conditions to be met in the design of instructional systems of high stability. The practices of modelling and simulation, drawn from Systems Technology, could be utilized by curriculum planners to achieve more efficient expression, communication, and manipulation of curriculum models.

DAVID PRATT*

System Theory, Systems Technology, and Curriculum Design

Introduction

Few subjects can have been as widely discussed, advocated, and denounced by educators as what is often called "the systems approach". It is symptomatic of the ills of education, as discipline and practice, that there have been few serious attempts by educators to understand the subject. While the advocates — with a few distinguished exceptions[1] — use systems thought primarily as a slogan generator, the antagonists bring nothing to mind more clearly than Defoe's observation that

> in his day there were 100,000 country fellows willing to fight to the death against Popery, without knowing whether Popery was a man or a horse.

The writer believes that the significance of systems thought for education is too great to be left to the editorialists. System theory, originating in biology, has revolutionized management science, communications, and planning. It has been responsible for the development of entire areas of study within physiology and ecology. Philosophy, geography, economics, political science, sociology, psychology, and psychiatry are among the disciplines directly affected. Education is in fact exceptional in having failed to come to grips with a set of concepts which have now been part of scientific thought for a generation. Yet few fields of study are in greater need of an injection of inspiration, which seems increasingly unlikely to come from within. What are needed above all are new coordinating and organizing principles, and if this applies to education in general, it applies especially to curriculum. Almost twenty years ago Goodlad stated that "Nowhere in education is there greater need for a conceptual system to guide decision-making than the field of curriculum."[2] This paper attempts to explore some of the ways in which systems thinking can provide such a conceptual system, both to illuminate the study of curriculum, and to guide the design of curricula.

System Theory and Systems Technology

It is necessary first to make a broad distinction between System Theory and Systems Technology. System Theory (or System Science), formulated by von Ber-

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* David Pratt is Associate Professor, Faculty of Education, Queen's University, Kingston, Ontario, Canada.

talanffy in the late 1930s in biology, was rapidly supported in the 1940s by work in Cybernetics by Wiener and Information Theory by Shannon. It deals with "scientific exploration and theory of systems in the various sciences . . . and principles applying to all systems."[3] Systems Technology (or Systems Engineering) owes much to Operations Research which emerged in World War II, as well as to Cybernetics and Decision Theory; it is concerned with the organization and control of man-made systems. Both System Theory and Systems Technology are context-independent; their application is not confined to any one area of human endeavor. The two fields have nourished one another, and the relationship between them is intricate, but they manifest a basic difference of intent. System Theory is concerned with explanation, Systems Technology with decision-making. To echo Marx, System Theorists seek to understand the world, Systems Technologists to change it.

It will not be necessary to examine either the history or the substance of Systems Theory or Technology in detail. However, a brief account of System Theory may help to establish a conceptual context for discussion of its curriculum applications.

General Systems Theory

System Theory represents one area of thought which was not forshadowed by Greek science. In fact, it basic premises constitute a rejection of the analytical, reductionist science of Aristotle.[4] The basic thesis of General System Theory is that the laws governing living systems are not reducible to the the laws of physics. In particular, living systems violate the Second Law of Thermodynamics.

According to this law, in any system entropy, or disorder, must always increase to a maximum; there is an inexorable trend from improbable to most probable states; heat passes in only one direction, from matter at a higher temperature to matter at a lower temperature; hence any organization of matter will break down progressively, like a sandcastle on the beach, until its boundary disappears, it becomes indistinguishable from the environment, and achieves equilibrium in a state of random disorder or sameness. On the broad scale, the solar system will eventually run down to an essentially inactive low-temperature equilibrium. However,

> Certain processes associated with life seem to go counter to this current. Within living organisms proteins are synthesized as well as denatured; gradients are established as well as neutralized; specific structures are created; behavior tends to go from random to specific in many learning processes, and on the grand scale biological evolution seems to give rise to ever-increasing ordered complexity in the development of higher species.[5]

The crucial difference between living and physical systems, according to General System Theory, lies in their relationship with the environment. Physical systems are "closed systems" which do not interact with their environment. (Strictly speaking, only open systems can properly be called systems.)[6] They absorb energy from the environment, store and transform it, and emit a product to the environment. Entropy always increases in physical systems; but in living systems it is the opposite of entropy — negentropy — which is developed; and negentropy is information.

The more advanced the organism, the greater its ability to process energy it absorbs as information, and this information is used to develop its organization hierarchically in the direction of elaboration and differentiation. While organization in physical matter constantly breaks down until a state of equilibrium is achieved, organization in living systems constantly increases. The natural state of an organism is not a static equilibrium, but a dynamic steady state of input and out-

put. Furthermore, living systems appear to direct themselves towards this state. Unlike physical systems, which are deterministic, organisms have a capability, known as equifinality, to achieve the same steady state in different ways and from differing initial conditions.[7] If a piece is cut out of the humerus of an amphibian limb, the bone will re-form an exact copy of its previous shape.[8] A sea-urchin embryo, cut in half, will produce two small but perfectly-formed sea-urchins.[9] Similarly, a human may originate from a whole or, as in the case of indentical twins, from half an ovum. Once the steady state is achieved, it is maintained by self-regulation. Thus, while physical matter is governed by randomness, reacting according to physical laws, living systems behave, and their behavior is characterized by goal-directedness; they can validly be termed teleological systems. In the long run, organisms, like the universe of which they are part, die, decay, and conform to the Second Law of Thermodynamics. But during their lives their primary features are the reverse of thermodynamic entropy — purpose and organization.

Application to Curriculum

Is it plausible that any aspects of System Theory could have significance for the study of curriculum? Early in its history, System Theory showed that its significance was not limited to biological systems, but that its concepts could be productively applied to contrived, social, and symbolic systems. The key question, then, is: Is curriculum a system? According to Boulding, whatever is not chaos is system.[10] Is curriculum chaos? Regrettably, one would have to say that it frequently is; but is it necessarily so? A definition of both System and Curriculum is appropriate at this point.

Many definitions of System exist. The four characteristics that are included in most definitions are organization, interaction, wholeness, and purpose. Accordingly, we may define a system as follows:

> A system is a complex of interacting and interdependent processes serving a common purpose and constituting a unified whole.

There is much less agreement about the definition of curriculum. In fact, failure to agree on what is being discussed is both a cause and a consequence of the present state of curriculum study. The following definition is stipulated for use in this discussion:

> A curriculum is an organized set of formal educational and/or training intentions.

The intentions referred to in the definition are not only intentions as to what students will learn, but also intentions as to what is to be taught, what materials are to be used, what methods of assessment will be employed, etc. "Intentions" limits the curriculum to plans, blueprints, or proposals. A curriculum is not activities but ideas, usually written down but possibly within someone's head. Teaching and learning are not part of the curriculum; they are part of the program that results when a curriculum is implemented. "Formal" limits curriculum to deliberate intentions, and hence provides a much more restricted definition than the well-known "all the experiences that a learner has under the guidance of the school."[11] That the intentions are organized implies that a curriculum must show the relationships among such elements as aims, objectives, evaluation, subject-matter, cost analysis, and so on. Both education and training are included in the definition to prevent the misunderstanding inevitable if one is omitted.

Curriculum design is the art and science of designing curricula. Its inputs are information about reality and creative thought. Its output is curriculum. Its func-

tions are information processing and decision making. Curriculum design is systematic to the extent that its processes are coherent and interactive, and unified by a common purpose. The same is true of the instructional system (or program) into which the curriculum is an input (Figure 1).

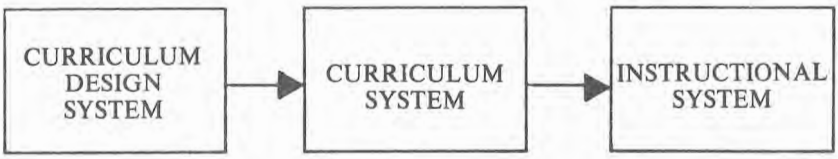

Figure 1

Input and Output of the Curriculum System

This paper is concerned with the first two of these three systems, and the extent to which they can draw theoretical insight from System Theory, and operating principles from Systems Technology. It may be noted at this point that none of these three systems is a natural system. They are all man-made, "artificial", or contrived systems, although they interact with such natural systems as human learing on the one hand and institutional politics on the other. The basic question, therefore, is not, "In what ways are system characteristics manifested in curricula?" but "With what benefit can systems principles be introduced into curriculum and its design?"

In this paper, a limited number of systems concepts and principles are examined. All of the concepts are important in Systems Technology, although they represent three different pedigrees. Wholeness and coherence are basic concepts in System Theory and are discussed from that point of view. Feedback and the Law of Requisite Variety are central principles in Cybernetics. Modelling and Simulation are practices developed by Systems Engineers.

Wholeness and Coherence

General System Theory is, in the words of Bertalanffy, "a general science of wholeness."[12] Although the attempt to produce scientific syntheses or general theories had many historical precursors, from Leibnitz and Spencer in science to Ritschl and Tillich in theology, the contribution of System Theory in this respect is regarded by some commentators as revolutionary:

> Before the revolution in thought that made possible the use of teleological concepts as a methodological key to open doors previously closed to science, scientists tended to derive their understanding of the functioning of the whole from the structure of the parts and the structural relationships between them. Today we increasingly tend to derive our understanding of the structure of the parts of a system from an understanding of the function of the whole.[13]

Classical science tended to treat wholes as aggregates. In an aggregate, the parts are added, so that the whole can be readily understood as the sum of its parts. In a system, on the other hand, the parts are organized: the whole is more than the sum of its parts. "A human being can write or run, but none of its parts can."[14] Emphasis on wholeness and coherence — in a word, systemness — was what Plato sought in medicine 2500 years ago:

> The great error in the treatment of the human body is that physicians are ignorant of the whole. For the part can never be well unless the whole is well.

Systems thought is at least partly responsible for medicine's gradual retrieval of this insight of Plato.

Every system is itself a subsystem of a larger system; there is an ultimate system only if the universe itself is finite. The environment of a given system is, strictly speaking, everything in the universe which is outside the system. But in any particular investigation, the environment of interest consists of all those elements outside the studied system which significantly affect, or are affected by the system. Thus what constitutes the system, and what the environment, is determined by the nature and scope of an investigation. If a cell is studied as a system, the organism is the environment; if a human being is the system of study, the ecosphere and sociosphere is the environment. For the curriculum designer, the school administration system is part of the environment; but for the social planner, curriculum design is merely a subsystem of the school administration subsystem.

A system manages its own complexity by hierarchical organization. Weiss describes hierarchy as "a biological necessity". He points to the human brain as an example of an extraordinarily complex, hierarchically organized system.

> The average cell in your body. . .contains about 10^5 macromolecules. Your brain alone contains about 10^{10} cells, hence about 10^{15} macromolecules. . . .Each nerve cell in the brain receives an average of 10^4 connections from other brain cells, and although the cells themselves retain their individuality, their macromolecular contingent is renewed about 10^4 times in a lifetime. . . .Could you actually believe that such an astronomic number of elements. . .could ever guarantee to you your sense of identity and constancy in life without this constancy being insured by a superordinated principle of integration?[15]

The wellbeing of a system depends upon its remaining an open system, exchanging energy with its environment. It also depends upon its subsystems remaining open and exchanging information with one another. The processes of elaboration, differentiation, and specialization, by which organic systems develop, present the threat that the interaction among some subsystems will be inhibited by the increasing complexity of the information paths. This is, in fact, what appears to happen in education. In the words of a management scientist:

> Education is *not* carried out by a system but by an *antisystem*— a deliberately noninteractive set of institutions each of which is carved up into equally noninteractive components.[16]

"Partiality", according to Schwab a characteristic defect of curriculum study, prevails at both the institutional and intellectual level.[17] The gulf between educational administrators and learning theorists, for example, is rarely bridged. This disintegration may be one of the reasons why research advances have so little effect on the practices of schooling. The science projects of the 1960s tended in many cases to treat one subsystem of curriculum — subject matter — as if it were homologous with the total system. In recent years, objectives have assumed that role; one well-known definition of curriculum is in fact "a structured series of intended learning outcomes."[18] The relationships among student needs, aims, objectives, content, evaluation, etc., are badly in need of articulation. And the failure to conceptualize clearly the relationships between curriculum intent and evaluation of student achievement is, I would argue, responsible for the exhausting and unproductive Behavioral Objectives controversy.[19]

All educational institutions nevertheless manifest many systemic qualities. One of these is conformity with LeChatelier's Principle: perturbations from the outside will result in a slight movement of the equilibrium point of the system to accommodate the change.[20] Those who believe that educational institutions can be revolutionized by introducing open areas, internal assessment, or student repre-

sentation on curriculum committees are usually surprised when implementation of their ideas produces nothing more than validation of LeChatelier's Principle. Thus the proponents of a British experiment in student-centered, integrated, thematic, and democratic curriculum making were dismayed when in a matter of weeks after inception of the experiment, students began to complain that "It's still the teacher telling you what to do," and subsequently "reverted fairly quickly to their familiar former roles."[21] Their experiences prompted the conclusion that

> The curriculum is best seen as a system, an organic whole, based upon a theory and associated organizational structures, roles, and relationships. . . .Any reform which leaves the basic theory and organizational structure unchallenged will inevitably effect only piecemeal, minimal change.[22]

There appear to be three possible futures for curriculum. One is to continue the process of disintegration, each subspecialization competing for diminishing resources of attention, prestige, and support. Another is to make vague appeals for gestaltic understandings in education, which assuages everyone's guilt while allowing people to proceed as hitherto. The third is to attempt to achieve a conceptualization of curriculum which does justice to its complexity as well as its unity as a dynamic system.

The arguments which have been presented to this point may be paraphrased in seven propositions:

1. Curriculum design is a contrived system, and is hence whatever men make it.
2. Curriculum design is a system for information processing and decision making.
3. The inputs to curriculum design are information about reality, and creative thought.
4. The output of curriculum design is curriculum.
5. Curriculum design is a subsystem of educational planning.
6. The environmental systems which are most significant to curriculum design are political, cultural, and social.
7. The health of a curriculum design system depends on its openness to its environment and among its subsystems.

Purpose

Living systems are characterized by pursuit of goals, and it is their goal-directedness that determines their unity and coherence.

> The most distinctive character of the behaviour of higher organisms is its goal-directedness, its apparent purposiveness. In fact, it is largely through this apparently teleological nature of their activities that living organisms betray their exceptional organization. And their position on the "scale of life" is largely determined by the degree to which they possess these characteristics.[23]

Human groups provide examples of systems whose unity is provided primarily by common goals. The character that distinguishes a marriage, a club, a political party, or a nation from the rest of the human environment is not so much geographical or cultural proximity as commonality of intent.[24]

If all living organisms are teleological, man is unique in being conscious of his goals, and hence can properly be said to be purposive. This is not to say that he is conscious of all his goals. Explanation of human behavior may, as Kaplan points out, be either motivational or functional, depending on whether the ends of the behavior are previsioned by the agent. But

> Activities that are not in some sense goal directed are precisely those, it seems to me, that are designated as meaningless.[25]

Substantial empirical support for the significance of goals in behavior has been provided by numerous experimental studies of human performance conducted over the past decade, many of them by Edwin Locke and his colleagues.[26] These studies have been almost uniformly ignored by the disputants on curriculum objectives. Their collective import was summarized by Hamner: "The most immediate, direct, motivational determinant of task performance is the subject's goal."[27] At a philosophical level, it could be suggested that the essence of man's humanity is that he not only seeks immediate purpose in his actions, but transcendent purpose, or meaning, in his life.

Purpose is of equal importance in contrived systems, but in this case the purpose must be explicit. "Mission definition" was one of the vital concepts inherited by Systems Technology from Operations Research, and wherever Systems Technology has been applied, in management, architecture, urban planning, law enforcement, agriculture, communications etc., the initial definition of purpose is regarded as critical.[28] When President Kennedy announced to Congress in 1961 that

> This nation should commit itself to achieving a goal, before this decade is out, of landing a man on the moon and returning him safely to earth

he was not only launching the most spectacular application of Systems Technology yet seen; he was also obeying the principle of clear and exact goal definition.

Contrived systems are, by consequence of their goal-directedness, centralized systems.

> A centralized system is one in which one subsystem plays a major or dominant role in the operation of the system. We may call this the leading part or say that the system is centered around this part. A small change in the leading part will then be reflected throughout the system, causing considerable change. It is like a trigger with a small change being amplified in the total system.[29]

Just as the brain is the leading part of the body, determining the behavior of every other part, the basic mission or goal is the leading part of a contrived system, determining the nature of every other subgoal and process in the system.

Viktor Frankl recognized the significance of these principles for his school of psychotherapy based on "the will to meaning". "Being human," he writes, "is always pointing beyond itself, is always directed at something or someone, other than itself" and "What man actually needs is not a tension-less state but rather the striving and struggling for some goal worthy of him."[30] The same principles suggest that a criterion for a humane, as well as effective, curriculum, will be a high degree of purpose, directiveness, or meaning. This has been part of the theme of at least one major contribution to the philosophy of curriculum.[31] Also implied is that the effectiveness of an instructional system will be a function of the degree to which the purpose or meaning of the curriculum is understood and supported by the learners, and consistently reflected in its parts. These implications run counter to the theses of those who appear to claim that the curriculum should be nondirective or nonintentional.[32] On the other hand, Systems Technology does not support those who advocate a single criterion — for example, behavioral definition — in evaluating goals. More than a decade ago, a pioneer of systems technology condemned

> The simple-minded view that the only requirement for setting good objectices is definiteness. That is, objectives are a good enough guide for action as they are emphatically stated (perhaps by shouting).[33]

It should be noted at this point that goal definition, despite its centrality, is not the first stage in the engineering of contrived systems. It belongs to the phase known as "development planning." The goal specifies the purpose that must be realized if a need is to be met. In most organisms both the needs and the purposes and their priority are instinctual. In contrived systems, the needs are determined by the processes of "program planning" and "exploratory planning."[34] "Needs assessment," as it is more commonly known in educational circles, provides the initial and most significant interface between the social environment and the system. The needs defined must be related to the goals of the superordinate system. Thus if the overall goal of social and of educational planning were "To enhance the quality of life", curriculum Needs Assessment would determine the specific human needs that curricula should meet to serve this end. In practice, the curriculum designer's task is made more political but less constrained by the fact that the superior systems rarely define their goals explicitly.

Complex systems are characterized by a hierarchical organization of subsystems; this necessitates, in contrived systems, determining priorities among subgoals. A lack of clarity about such priorities produces stressful competition among subgoals. Not all stress is harmful to systems; in fact, viable systems make constructive use of stress — muscle tone is an example.[35] Competition among subgoals at the same level may be healthy. It may be good for Ford to compete with General Motors for customers, and History with Yoga for students. Competition becomes damaging when a subsystem pursues its own goals at the expense of a superior system. "Suboptimization", as this is called, ultimately defeats the ends of the subsystem as well as those of the system. Cancer provides one instance. "Book-stacking" (a practice whereby students seek a competitive advantage by hiding required library reading from other students) is another. A principal who is determined at all costs to have his school win the most football matches, band competitions, or university scholarships, is encouraging suboptimization.

A possible strategy to avoid these problems in curriculum is to classify all curriculum goals as critical, important, or desirable. The school must, by definition, attempt to achieve all critical goals. Competition is legitimate only among important, and among trivial goals. Yoga competes with History, but not with Road Safety.

Failure to define the basic goal clearly is the best way to ensure conflict among sub-goals. Conversely, disputes regarding subgoals (means may also be regarded as subgoals) can be resolved by recursion to higher level goals until consensus is reached, and then working progressively down through the goal hierarchy. An example of this process is provided by the cabinet-level discussions in France on the future of Paris, in which deep division occurred in any discussion of subordinate goals. But once the goal of making Paris a global city was agreed, accord followed on such subordinate goals as to make Paris multilingual, which could not have been agreed if proposed in isolation.[36]

Five propositions are entailed or implied in the foregoing.

8. The basic goal of curriculum should be clearly defined.
9. Curriculum effectiveness depends on communicating goals to learners and winning their support.
10. Curriculum goals should be defined by needs assessment, and should advance the goals of superordinate systems.

11. Curriculum subgoals should reflect the basic curriculum goal, and should be ordered in priority.

12. No goal should be jeopardized by goals of lower priority.

Feedback

The concepts described so far could apply equally to static structures and to dynamic systems. The unique feature of dynamic systems is their capability for self-regulation, a capability that is realized through feedback.

Feedback is perhaps the best known and hence the most indiscriminately used systems concept. It is defined by Norbert Wiener as "a method of controlling a system by reinserting into it the results of its own performance."[37] Although the emergence of the formal study of self-regulating systems dates from the definition of the field of Cybernetics by Wiener in the late forties, feedback was used mechanically by James Watt in 1785, observed in physiology by 1885, and extensively described by 1939,[38] and has been employed in such domains as electronics and weaponry for more than sixty years.

Feedback is of two kinds, positive and negative. Positive feedback moves a system away from an existing state, negative feedback operates to restore equilibrium.

The domestic thermostat provides a familiar model of negative feedback. Let us suppose a thermostat is set to maintain temperature within a chamber between 68° and 72°F. and that the temperature of the environment is less than 68°. When the room temperature falls to 68°, the thermostat closes the switch activating the furnace. When the temperature reaches 72°, the switch opens, cutting off the furnace. The thermostat is a regulator or "servomechanism" which consumes very little power itself. In mathematical terms, a servomechanism operates by comparing an actual state (a) with a desired state (d) and feeding the difference (d - a) back into the system to restore equilibrium. In the thermostat example, there is a margin of tolerance of 4 degrees (Figure 2, curve 1); the thermostat intervenes intermit-

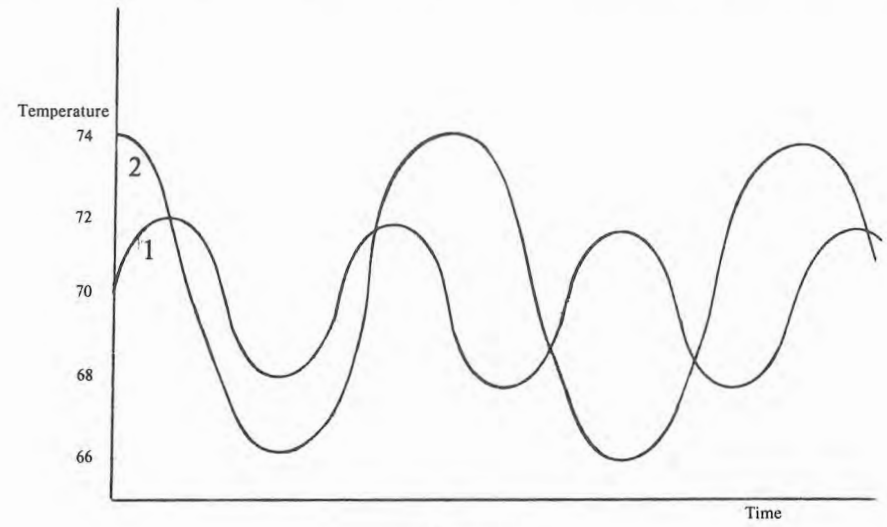

Figure 2

Temperature oscillation as a function of delay of feedback

tently at the top and bottom of the range, resulting in continuous oscillation of the temperature. If the thermostat were less precise, and could regulate the temperature only within 8 degrees (Figure 2, curve 2), the switch would be operated less frequently, that is, the feedback would be delayed, and greater oscillation would result. The result of breakdown of feedback in a system is catastrophe: runaway to zero or runaway to maximum. Failure of a thermostat results either in the temperature of the chamber falling until it approximates that of the environment (the system in fact disappears), or increasing until heat loss from the chamber equals the output of the furnace, or until the furnace burns out, the chamber catches fire, etc.

Figure 2 shows the relationship between delay in feedback and oscillation. In Figure 3, curve 1 is overdamped: great stability is obtained at a cost of long response time.[39] Curves 2 and 3 show increasing oscillation. In curve 4, the oscillation is out of control, producing catastrophe. Oscillatory behavior is a common feature of systems. Arctic lynxes and their prey, the snowshow hares, maintain a rhythmic oscillation in their numbers which is apparently due in part to the interaction between population and biochemical changes affecting fertility.[40] Stuttering can be artificially induced by delaying auditory feedback.[41] Tracking performance, as in driving a car, tends to oscillate; the oscillation is amplified as feedback is degraded by intoxication. Beer suggests that if governments act on information six months old when attempting to regulate economic fluctuation, they may stimulate the economy when it is recovering, and dampen it when it is declining, and will consequently amplify economic oscillation.[42] Finally, the swings in educational ideology show a classical pattern of oscillation.

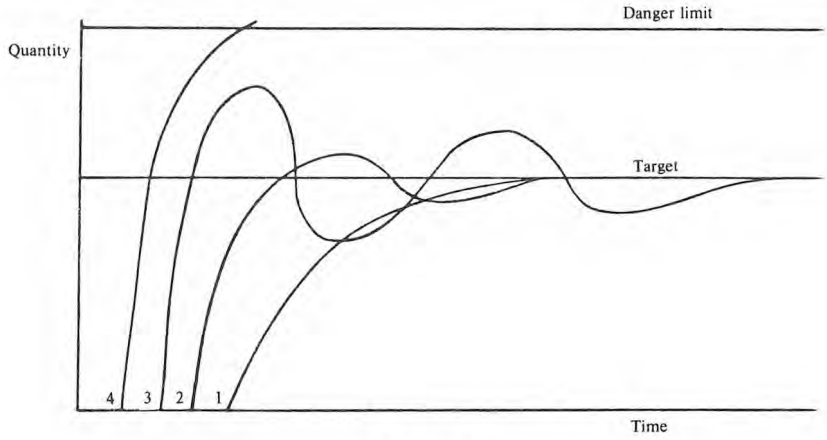

Figure 3

Patterns of oscillation

Thermoregulation in the human body provides an example of self-regulation in a natural system. When animals first left the oceans to live on land, they could no longer rely on the stable marine environment to maintain a constant body temperature. They took part of this environment within their systems, and developed more or less elaborate processes for self-regulation. In man, these processes are sensitive enough to enable him to withstand heat up to 150°F. and down to 20°F. unprotected for short periods without a change in internal body temperature. In a

cold environment, the posterior hypothalamus appears to act as the main regulator, receiving information from heat sensors in the skin;[43] increased adrenalin is secreted into the bloodstream, heart rate and respiration are accelerated, peripheral blood vessels are constricted, and blood pressure is raised. The heart is the main mechanism for maintaining body heat, but the body, as an "ultrastable" system, has a second line of defence; the hypothalamus can delay feedback between the cerebellum and the small muscles. This results in the symmetrical oscillation we know as tremor or shivering, which provides an additional source of heat to the body. In a hot environment, some of these processes are reversed. The anterior hypothalamus controls the thyroid gland which becomes less active, heart rate and blood pressure are decreased, and blood vessels in the limbs and body surface dilate. As a further defence, sweat can be excreted, the evaporation of which cools the skin. The system can be viewed as one which regulates itself by means of multiple feedback loops to maintain a constant output of 98.4 degrees. Other cybernetic systems maintain constant levels of sugar, water, acidity, carbon dioxide, and oxygen in the body.

The reader can easily think of other examples of systems which regulate themselves by means of negative feedback. Ecology provides numerous illustrations. Watt's flyball governor used centrifugal force to open and close a steam-valve, allowing constant performance of the engine despite changes in load. Biofeedback training enables a subject to learn how to control mental and physical states by amplifying feedback from body subsystems and presenting it to the subject in some perceptible form.[44] Numerous studies in physiology have demonstrated the power of the principle of feedback in describing human movement and motor skills.[45] The ability to pick up a lead weight or an egg, for example, to ride a bicycle, or to stand up without falling over, all rely on proprioceptive feedback.

Public discussion often mistakenly equates feedback with any kind of response, and considers only negative feedback. But many examples can be found of positive feedback, where movement away from equilibrium is fed back into the system to produce further movement in the same direction. Gunnar Myrdal observed a positive feedback system when he commented on the vicious circle of racial discrimination in the United States: discrimination produced degradation which was used to justify further discrimination.[46] The "knowledge explosion," the rate of cultural change, the growth of bacteria, multiplication of rabbits, and nuclear chain reactions, are all examples of positive feedback. So are crowd behavior, vendettas, and wars. Civil unrest and repression follow a classical pattern of positive feedback, often resulting in catastrophe. Inflation is fuelled by positive feedback, and since inflation is not self-limiting it remains to be seen whether it will be externally controlled or will runaway to maximum, i.e., collapse of the monetary system. Both positive and negative feedback are essential to the learning process. Love and hate manifest elements of positive feedback, and the intuitive recognition of this may be the basis of the Christian ethic.

Charges of rigidity, totalitarianism, and inability to respond to the unanticipated are often leveled at what are reputed to be systems models of curriculum. Such changes apply to static models, which are in effect not systems at all. Program Evaluation and Review Technique provides one such model, from which feedback is explicitly excluded[47] and which cannot therefore be adaptive or self-regulating. Several feedback loops would be expected both within a curriculum design system and between the system and the environment. In a changing society, the process of needs assessment and definition of basic goals must be cyclical if the curriculum is

to achieve a steady state. Feedback loops must also be established between such subsystems as specific objectives and subject matter, and between assessed achievement and performance criteria. All significant outputs of the instructional system must be fed back into the curriculum design system, so that it can both adjust for areas of underachievement, and utilize information about unexpected outcomes. Most of these loops will carry negative feedback. But in such an event as the curriculum producing unexpected benefits, the feedback could be positive: the information will imply not "change what you are doing" but "do more of what you are doing."

It was noted earlier that negative feedback operates by determining system error (d-a) and feeding it back into the system. To determine the system error, two quantities must be determined: what is desired, and what is produced. A dynamic curriculum system thus depends on exact definition of desired outputs, and exact measurement of actual outputs.

The following propositions are implied:

13. For a curriculum to achieve a steady state, clear delineation of goals and criteria of performance is essential.

14. The effectiveness of a curriculum will depend on feedback among its subsystems.

15. The appropriateness or validity of a curriculum will depend on feedback between the curriculum design system and the environment.

16. A curriculum designed to maintain a steady state of high learner achievement must provide for frequent monitoring and rapid adaptation of instruction.

17. Negative feedback can call attention to unanticipated deficiencies to be remedied; positive feedback to unexpected benefits to be taken advantage of.

The law of requisite variety

The variety of a system is the number of possible states of a system. The function of feedback is to regulate this variety so as to produce a consistent output. A classroom of students has almost infinite variety. The task of the designer of curriculum systems is to plan regulative mechanisms which enable the system to produce a low-variety output of skill, knowledge, attitude, etc. To take a simplistic example: prior to instruction, responses to the question, What is the cube root of 343? contain high variety; after instruction, variety is reduced to nil: all the answers are "7". Before instruction, the students' drawings of a tree might range from imaginative to stereo-typed; after instruction, all might be characterized by a high degree of creative imagination, although the actual drawings might vary greatly in form.

In practice, the effect of classroom instruction often seem to be to increase variety of output. Figure 4 illustrates the common situation where the able students learn a great deal more than the weaker students; the distance between the groups is increased. In contradistinction to this model, the "mastery model" of instructional design advocates decreased variety in achievement, as illustrated in Figure 5. A great deal of variety regulation in the system is necessary to achieve this kind of outcome.

The Law of Requisite Variety, or Ashby's Law, is regarded by Beer as of equal importance for organization as is the law of gravity for physics.[48] It states that "only variety can destroy variety"[49] or "only variety can absorb variety."[50] The law can

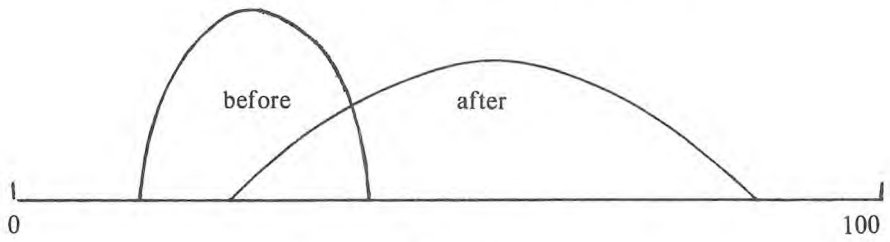

Figure 4
Conventional instruction

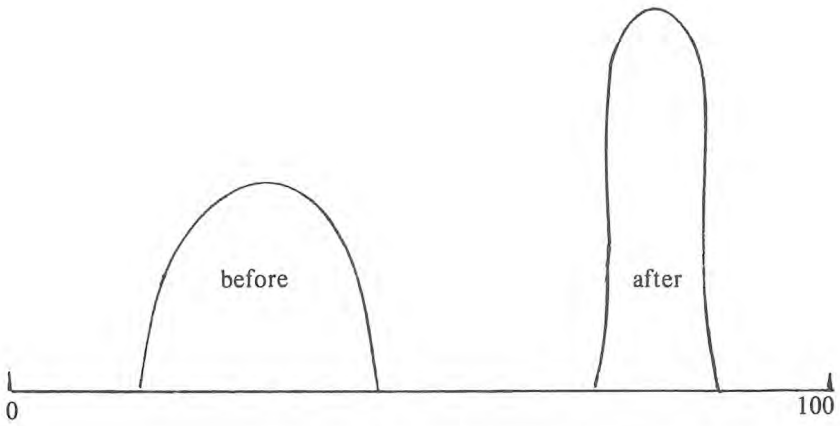

Figure 5
Mastery model of instruction

be applied in two ways to reduce variety in a system: by attenuating the input variety, or by amplifying regulative variety.

There appear to be five main kinds of input variety that are of critical concern to the designer of curriculum. These are student ability, background, developmental level, motivation, and preferred learning style. The pattern illustrated in Figure 4 occurs because this variety remains unregulated in the system and produces high variety in the output. These five characteristics are to a great extent context-dependent. A pupil may be well motivated in art, but poorly in mathematics. He may have high athletic ability, but low ability in languages. His grasp of scientific principles may be highly developed, but his moral development immature. Consequently, the variety must be regulated differently for different curricula, depending on the subject-matter and instructional methodology to be employed, and the degree of individualization to be used in instruction.

It is a historical curiosity that the three kinds of variety which schools in many countries have regulated most vigorously have been age, sex, and social class, none of which it is normally necessary to regulate on curriculum grounds. In recent years, prerequisites have been used to establish a common background in the subject taught, and optional subjects introduced, in which some commonality

of motivation is expected. Sometimes variety is attenuated within a class, rather than at the admission point; bright students are held back by "busy work", or slow students are ignored.

Attenuation of variety is generally less satisfactory in social systems than in mechanical systems. The governor in Watt's steam engine would close the steam input-valve in order to maintain a steady state in the engine in the event of reduced load. The steam is stored in the boiler; there is at worst an "opportunity cost" in the form of unused capability. It is difficult for educational systems to "store" those who are excluded from opportunities without a damaging social cost. More commonly, an alternative supposedly more appropriate experience is provided for them. In terms of the system as a whole, this is amplification of regulative variety.

The application of Ashby's law to curriculum are legion. Let us limit description to four examples, one example of attenuation of input variety — prerequisites — and three examples of amplification of regulative variety — flexible time allotment, remediation, and redundancy.

Prerequisites have earned a bad name through abuse by elitist institutions. But two kinds of learner variety — background and developmental level, cannot be dealt with efficiently in any other way. A student who has not mastered addition cannot master multiplication. A student who has not yet developed the concept of historical time can only gain accidental benefit from the study of history. The human tendency to attenuate variety tempts teachers, if given the opportunity, to exclude any students who threaten the classroom equilibrium. For this reason, the law of parsimony should govern definition of prerequisites. But the price of ignoring legitimate prerequisites is an unstable or inefficient instructional system. For social and ethical reasons, schools should attempt to make good deficiencies in the background of students who fail to meet prerequisites in courses they want or need. In other words, the system as a whole should amplify its regulative variety to accommodate students temporarily precluded from a given subsystem.

Student ability is principally reflected in rate of learning. More able pupils learn faster than less able ones. This is obvious. But if it is obvious, why do schools almost universally organize courses for students widely ranging in ability in uniform blocks of time? The answer can only be: because schools are willing to tolerate a high-variety output. Some schools, troubled by this consideration, have rediscovered peer tutoring, forgotten since the nineteenth century. The more able students tutor the less able ones; this kills two birds with one stone; it slows down the able students and speeds up the slow ones. Variety is attenuated on the one hand, amplified on the other, resulting in a kind of instructional regression towards the mean. There is more to be said for peer tutoring than this description implies; but the logical response to maintaining stable output in the face of different learning speeds would seem in the first instance to be to allow the speed of student progress to vary. Administration of time in large inflexible blocks is a holdover in schools from the precomputer age. In fact, no computer would be needed to structure large parts of the school timetable in six-week modules, new modules staggered to begin every two weeks, so that students could advance to another course after six, four, or two weeks, depending on the speed at which mastery was achieved. There is not space here to explore the possibilities this offers. Sufficient to say that it is a good example of amplifying regulative variety.

Remediation is a feature of most teaching, although it tends to be somewhat haphazard, ad hoc, and unduly delayed. Academic failure is subject to positive

feedback. Inability to grasp one concept, principle, or procedure often guarantees failure at the next step — a runaway to zero process. To prevent this, frequent monitoring and rapid remediation are necessary, if consistently high achievement is to be realized. To wait until the end of a semester or year to assess achievement is to build failure into the system. The remediation must also be predesigned; it is not practical to wait until the deficiency is discovered to design a remedial unit. And if the system is to be ultrastable it must have a second feedback loop to deal with those pupils missed by the first. Computer assisted instruction, with its capability for continuous monitoring and immediate remediation, is in this respect ideal; so is a class size of one. Teachers working with such advantages do not need systems techniques for amplifying regulative variety.

Redundancy is deliberately built in to complex engineering systems. It is the only alternative to an often unattainable policy of "zero defects". Alternative modes for mission-critical elements are built in to spacecraft; if one fails, another takes over.[51] Social and natural systems usually have several ways of achieving the same end. The simplest ways are used as a matter of course; progressively more expensive ones are brought into play in emergency. The chemical changes that take place in an animal in danger are an example of this. Another commonly cited instance is the Battle of the Bulge, where the American army cooks put down their ladles and picked up rifles as the battle reached a crisis.[52]

In instructional systems, all critical elements must likewise be protected by redundancy. In remediation, redundancy occurs in series, as increasingly intensive and individualized assistance is given to learners who fall below critical levels of achievement. In classroom teaching, redundancy is applied in parallel. Since students with different personalities and social outlook learn and are motivated best by different methods and subject matter,[53] and this variety cannot easily be attenuated, the teacher must amplify regulative variety by using a range of methods and content to achieve any given goal.

A number of propositions follow.

18. Curriculum systems aim to produce a low-variety output, given high-variety input.

19. To produce low-variety output, curricula must be designed to regulate variety.

20. The main kinds of variety to be regulated are ability, background, motivation, developmental level, and preferred learning style.

21. Variety in student background and developmental level are best regulated by attentuating input variety.

22. Where input variety is attenuated, the variety of the superordinate system should be amplified to accommodate excluded students.

23. Ability and preferred learning style are best regulated by amplifying regulative variety.

24. Motivation can be regulated by either or both strategies.

Modeling and simulation

A model is a simplified representation of reality, made in order to understand, predict, describe, communicate, and control aspects of the phenomenon represented. "The applied scientist is primarily a model builder."[54] He uses any of three basic kinds of model: visual, verbal, and mathematical. Visual models appear to have their origin in the brain's right hemisphere, sometimes called "the intuitive

brain," verbal and mathematical models in the left hemisphere or "rational brain."[55] Man's artistic development has been governed by visual models; his philosophical and scientific progress by verbal and mathematical models.

The models used in educational practice have drawn heavily on intuition. "Any qualified teacher can design a good curriculum" expresses a model based on an intuitive perception of reality, just as "the sun moves round the earth" expresses an intuitively derived model. The models used in educational theory have typically been verbal models. This may be either cause or symptom of education's prescientific limitations. On the one hand, verbal models are inadequate for rapid and accurate communication. On the other hand, the multichannel capacity of language — overtones and undertones, images, connotations, and metaphors — which make it so subtle an instrument in the hands of a poet, also make for vagueness and ambiguity. These difficulties are exacerbated in education by refusal of educators to agree on definitions of common-language terms, resistance to the use of new and exact terms as "jargon", and widespread contamination of educational discourse by slogans.

Verbal language is essentially an aural form of communication. Even written language, although its orgins were pictographic, developed as a visual representation of spoken words. The major deficiency of language for model building is that it cannot express a complex of relationships simultaneously; the best it can usually do is to produce a string of statements. The efficacy of visual models, by contrast, can be illustrated by reference to the topographic map, which is one of the oldest forms of graphic analogue. A few square inches of topographic map can communicate very efficiently a complex netword of spatial relationships which pages of prose could not do efficiently or accurately. The eye is just capable of decoding information faster than the ear. Here is a capability education can exploit.

The kind of model preferred by systems technologists has tended to be the block diagram or flowchart. Its immediate parent was the electrical circuit diagram, developed at the turn of this century, but prototypes are found in the "family trees" used as early as the fifteenth century to illustrate complicated relationships of consanguinity.[56]

Systems flowcharts usually employ both text and images. Some branches of systems technology use signal-flow graphs which combine visual and mathematical symbols as well purely mathematical models. The extent to which mathematical models can be validly applied is an indicator of the exactness of a science; for curriculum, such a day is distant. But at the present stage of the field, curriculum could helpfully adopt the use of flowchart models.

It is unfortunate that, as with many other aspects of systems technology, a half-understood misapplication of flowchart models has brought the practice into disrepute. The kind of flowchart often found in curriculum writings is illustrated in Figure 6. Such misuse of flowchart modelling is counterproductive. A model in which reciprocal exchange of information occurs among five elements can be more efficiently described in verbal than in graphic form. But such a model is of little value, for it fails to show the sequence and direction of information flow which is the essence of a system. It is unlikely to advance understanding or to guide decision-making.

Graphic modelling of curriculum has been pioneered by Silvern.[57] The principles

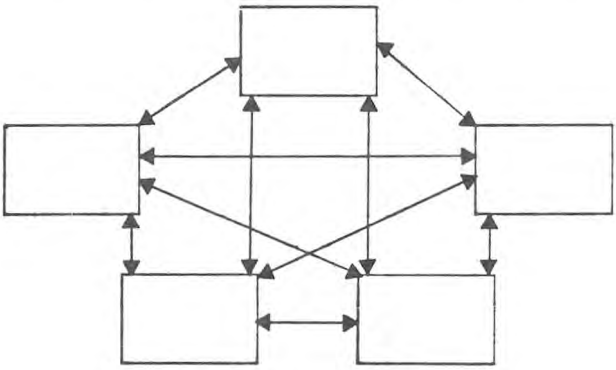

Figure 6

Counterproductive flowchart model

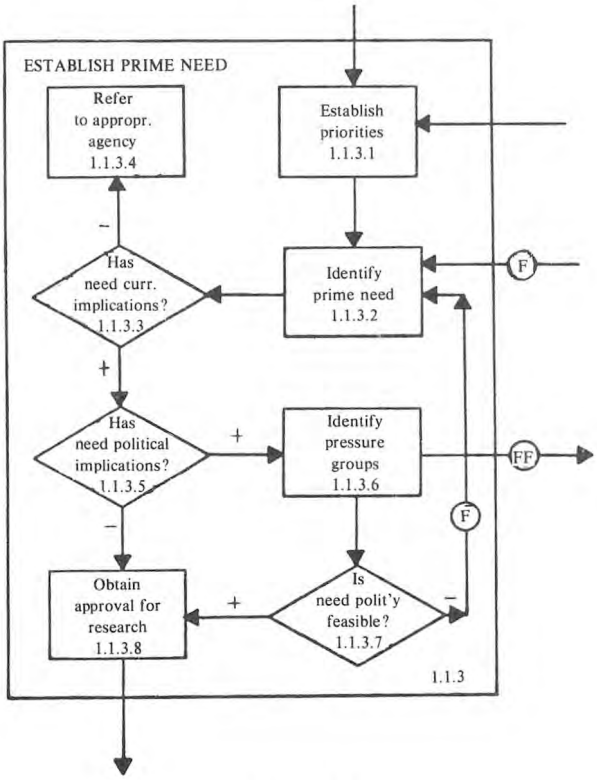

Figure 7

Subsystem of Needs Assessment Subsystem

described below are adapted in part from LOGOS (Language for Optimizing Graphically Ordered Systems) developed by Silvern.

Curriculum design was described above as a system for information processing and decision making. Curriculum design models should therefore be able to repre-

sent processes, decisions, and the relationships between them. Following the general conventions of electrical circuit and computer diagrams, process functions are represented by rectangles, decision functions by diamonds, and information paths by arrowed lines. The function symbols enclose verbal description in the form of commands and binary questions, and are numbered serially for identification. Feedback and feedforward paths are identified by initials. Subsystems are demarcated by rectangles. This brief description of the symbology will enable the reader to follow the flowchart in Figure 7.

The first subsystem of a Curriculum Design System might be termed "Prepare development capability" (1.0). Its own first subsystem (1.1) is "Determine need". Figure 7 shows the third subsystem (1.1.3) of the "Determine need" subsystem. Previous subsystems indicated areas of need either by general assessment or by identification of a specific problem. Subsystem 1.1.3 orders the decisions the curriculum designer must make in determining priorities and curricular and political implications prior to embarking on research into the need.

Flowchart models facilitate both analysis and synthesis. Once a model has been conceptualized in barest form, it can be progressively elaborated by analysing subsystems into their component functions. This process continues until a level of detail has been achieved appropriate to the task in hand. Conversely, the overall system model presents to the observer the whole system simultaneously. Committing a model to paper in graphic form highlights lacunae in the designer's logic and encourages a clarity of thought which would be welcome in curriculum. At the same time, the growth of this medium for expression of curriculum models holds out the possibility of facilitation of communication among curriculum workers.

Once a model has been produced, it can be tested and "debugged" by means of simulation. Aeronautical engineers discovered early in the century that testing aircraft in the air was expensive: it was cheaper to test them on the ground in a wind tunnel. Ultimately the wind tunnel gave way to computer simulation, in which all the variables could be programmed and manipulated mathematically. Curriculum models are rarely exact enough to allow mathematical simulation, although a simple example is given in Figure 8. The figure assumes that a course consisting of four consecutive units has been designed. Each unit is prerequisite to the one that follows. An estimate is made of the proportion of the group who will succeed in each unit, given success in the previous unit. In Figure 8 estimates of .95, .8, .9, and .75 are made for the four units. The proportion of those entering who complete the whole course successfully would therefore be .513. The designers could use this figure to calculate how many qualified entrants would have to be admited to provide a given number of qualified graduates. More probably, the designers would be dissatisfied with this result, and would manipulate the variables to produce a different result.

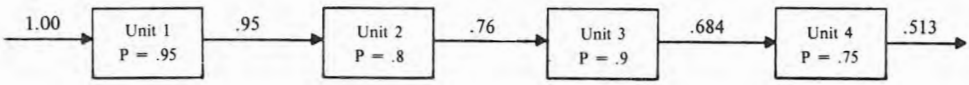

Figure 8

Mathematized model

The method of simulating curriculum models which is likely to be most effective given the present state of the curriculum art is "narration simulation"[58] or "talk-through technique."[59] In this procedure, a hypothetical problem is "talked through" a model. Examples exist in the literature of various educational problems which have been fed through curriculum models in narration simulation. A recent publication describes narration simulations in such areas as assessment of need for nutrition education, computer-managed program development, education of the handicapped, military curriculum evaluation, and career education.[60] The simulation process allows the designer to check the fit of the model to a real-world situation. Additional rigor is provided by having a simulation conducted by people who understand the model but do not share the designer's commitment to it. Simulation is not a substitute for pilot and field testing of curricula, but it does provide a means by which some of the faults in a model can be corrected before it is tried out with actual students.

In summary:

25. Models of curriculum should enhance both synthesis and analysis, showing the wholeness of the system and the relationships among its components to the required level of detail.
26. These requirements cannot be met by exclusively verbal models; but the field is not yet sufficiently sophisticated to allow much scope for exclusively mathematical models.
27. Verbal-symbolic flowchart models can meet these requirements, and hold the promise of enhancing self-expression and communication among curriculum thinkers.
28. The development of a model allows the curriculum worker to test the fit of his model to reality through simulation.

Conclusion

Joseph Schwab described the field of curriculum as moribund in 1969, and little has subsequently occurred to suggest a revision in that judgment. It is arguable that this state is of two thousand years' standing. In what ways are the processes by which teachers design their teaching different now than in the days of Tertullian or even Aristotle? Now as then the typical process is one of intuitive selection of low-variety strategies aimed to achieve a mixed level of success with respect to arbitrarily chosen and ill-defined goals. The dramatic advances in science and technology of the past two decades have had only a trivial and spillover effect, in the form of intellectual and physical gadgetry welcommed by some educators and resisted by others. But indeed, few advances can be expected in the field of curriculum design so long as it remains invisible. It is still a minority of educators who have a conception design as a distinct and content-free field of praxis.

Most of the efforts that have been made to advance curriculum thought in this century have attempted by means of academic introspection to develop the field from within the boundaries of educational thinking. In an age of intellectual crossbreeding and mutation, "curriculum theory" has become an ingrown, closed system, and is now dying of haemophilia. It is time to look beyond these self-imposed and anachronistic boundaries. It has been the theme of this paper that, in scanning the intellectual horizon for signs of rescue, systems theory and technology present possibilities that cannot be ignored.

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