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ABSTRACT

Systems concepts are useful in rethinking and reorganizing the structure of education. The author presents a popular interpretation of the systems approach to problem solving. He uses a general systems theory to compare the attributes of a school system and a computer system. He uses the idea of a critical subsystem to prepare a table of comparison which points up the discrepancies in progress between the two systems. Based on this comparison table he makes suggestions for areas of action to allow education to progress to its technological limits. He urges analytic systems studies as a continuing activity in the education field. (JY)

Systems Analysis in Education

by Richard E. Speagle*

Prologue

"System", thanks to wide military usage, has become a prestigous "in" term and is loosely dropped into ordinary conversation to lend it an aura of sophistication. At the opposite pole of usage, formal systems theory is an abstract topic with closely reasoned concepts emerging as an advanced field in higher mathematics.

This exposition is organized in four sections to:

(1) present a popular interpretation of the systems approach;

(2) use general systems theory to explain why the computer is a better learner (and reader) than "Johnny";

(3) obtain cues for needed remedial action in education through a cross-system comparison of the typical computer installation and school; and

(4) urge analytic systems studies as a continuing activity in the education field.

The reader-in-a-hurry may skip parts (2) and (3), trading off a gain in time against a loss in becoming more fully initiated into the workings of the systems approach.

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(1) A Popular Presentation of Systems

Despite their at times forbidding aspects, systems concepts are highly useful for the purpose at hand -- rethinking and reorganizing the education function. At an intermediate level between theory and nonsense, a common sense version may be outlined with adequate precision out of which will grow a more formal definition later on.

In most minds the term "educational system" conjures up an image of school facilities; teachers, students, and administrators; course materials, and instructional techniques. Other "outside" elements admittedly are influential -- to use jargon, the educational system is a "subsystem" of the larger social system -- but many people choose to view such influences as marginal rather than central.

But are they? And who says so? Scientific tests (and future R&D) may challenge the conventional wisdom as to what is or is not crucial to a child's learning. To take a simple example, the ease with which a youngster absorbs his lessons may be deeply influenced by his food habits and by parental harmony at home. Moreover, temperature in the classroom, distance and mode of travel to school, and the degree of discipline enforced are other vital variables.

An organized, broad-gauged attack on the task of instruction -- a "systems approach" -- makes traditional boundaries and definitions crumble. If nutrition and family relationships prove important, a breakfast and a mental health program must enter the definition of a complete "school system", and similarly with other "extraneous" influences. The potential impact of and need for this type of systematic thinking to solve problems like that of the ghetto or the rural school is obvious.

General systems analysis, defined as the application of systems theory to the solution of problems, is a three-stage procedure which:

--first, asks about the objectives of the job to be done;

--second, searches for the most efficient way of doing it, and

--third, evaluates performance.

Under a "systems approach", the analysis surveys the entire terrain without preconceived limitations, and examines all major premises. In tradition-bound education, as in many other fields, this is not being done, but now may be the time to start. In an important and broad sense, "instructional technology" means nothing more, nor indeed less, than a thoroughly rational approach to education.

The first stage of educational systems analysis, dealing with the question of objectives, was covered in an earlier chapter on R&D.

The second stage, the search for the best alternative means of instruction, blankets a series of techniques known collectively as operations research (OR). Generally, OR practitioners use such

tools (largely mathematical) as linear programming, game theory, queuing theory, simulation, statistical decision techniques and cost-benefit analysis, to name only a few.

In school systems, OR finds its greatest use in the logistics area, including the configuration of computers and terminals that play such a large role in CAI. However, one of the OR techniques, cost-benefit analysis, is of more than routine interest because it probes deeply into the process designs of instruction whenever several alternatives, and media related thereto, compete for doing a given teaching job. This makes cost-benefit comparisons of sufficient importance to deserve a separate chapter.

The third stage of systems analysis, evaluation and control of instructional performance, is a follow-on to decisions about ways and means, and consists of two parts:

(1) the design of measures and measuring methods;

(2) the actual measurement procedure for feedback and control of activities.

A design for measuring "classroom" results must be built into each teaching experiment, and measures so validated subsequently become tools in finding optimal teaching techniques. The logical place to discuss this topic, therefore, is under cost-benefit analysis. The testing operation itself, once viable measures exist, is relatively routine and needs no separate elaboration in this study.

The much publicized planning-programming-budgeting (PPB) technique, increasingly used by government agencies, is an attempt to put public expenditures on a rational or performance basis through a systems approach. Broadly speaking, the initial "P" represents the first stage of systems analysis in a fiscal setting; the second "P" begins the second ways-and-means stage and the final "B" -- budgeting -- defines program details of organization and scheduling in terms of dollars required.

The third or evaluation stage of systems analysis is undertaken by administrative action, usually by internal audits and later by outside review. In the federal government, the latter step comes under the jurisdiction of the Budget Bureau and the General Accounting Office.

Other terminology for applying systems analysis to public expenditures includes "program" and "performance" budgeting. A trap to be avoided consists of adopting the outward form of program budgeting by calling everything that is now being done a "program," while blithely ignoring any substantive attention to systems thinking. In that case, the term "program" becomes simply an empty box tagged with a promising but deceptive label.

The Field of Systems Analysis in Education

The potential, breadth and power of systems analysis applied to education is perhaps best illustrated by listing the major structural components which this approach brings under surveillance as it investigates the feasibility and promise of the new instructional media. The list is not exhaustive, but includes the following:

Components...	...and their role in the system
(1) Educational goals and objectives...	Goals, the broader concept, identify reasons for the expenditure of scarce resources in education rather than, say, industrial production. Objectives define the task of instruction broken down into smaller steps.
(2) Learning theory...	...furnishes a body of scientific principles which explain learning behavior and orient instruction.
(3) Teaching technology...	...provides an efficient instrumentation of instructional activities through various media.
(4) Educational testing...	...measures learning performance in the broadest sense, and thereby helps in the evaluation of (1), (2), and (3).

(5) Educational economics...	...furnishes data for costing input and valuing educational output; helps to determine sources and uses of funds in education.
(6) Teacher training...	...produces qualified human resources for the educational enterprise.
(7) Student population...	...constitutes the "raw material" to which educational processes are applied.
(8) School administration and faculty...	...represent attitudes and vested interests that must be reckoned with in any change of existing school arrangements.
(9) Education industry...	...develops and sells teaching devices, school supplies, and educational facilities.
(10) Organization of educational research...	...helps determine the rate and quality and data output in (2).

(11) National manpower needs......define job opportunities for graduates and helped to direct educational objectives in (1).

(12) Student home environment.....influences motivation to learning through living conditions and parental attitudes.

(13) Educational politics... ...recognizes the role of decision makers and their constitutents in formulating educational policies, subject to (1), (5), and (8).

(14) Educational strategy... ...searches for a combination of above elements to achieve educational goals of (1) in the most effective manner.

It would be tempting to wade right in and begin outlining programs under each of these headings but that is not feasible, being the very kind of comprehensive (and costly) systems study that flows as an urgent recommendation from later sections of this chapter. For the moment, having arrived at this panoramic viewpoint, additional insights into the systems approach can only be gained at the cost of stepping up the rigor of the exposition, taking care to keep it as non-technical as possible.

(2a) Computer and School Systems Compared

In its most general meaning, a system is a set of inter-related and interacting units having some properties in common. The state of each unit -- the current condition of any characteristic that is subject to variation -- depends in some sense on that of all the others.

Schools may be considered as living systems, a special category of concrete systems that exist in physical space and move forward in its time dimension. The fundamental binding agent of a school system, and the"glue" as it were of any system, is information (defined below) carried along on moving markers or "information-bearers" in a flow known as a communication process. Markers are physical entities or matter-energy, like a letter or electronic impulse, whose movement over space is defined as "action".

The principal function of the school system prototype is to produce and facilitate "learning", which is essentially the receipt, processing, storage and retrieval of information by a chosen clientele, the students. For this purpose the school system uses "specially patterned transmissions of information", a b-oad expression for "teaching" activities. These constitute an inter-mediate output of specialized system components, the teaching media.

Teaching output takes the form of signals and messages, the latter being simply a cluster of signals, which travel via audio waves, gestures, electric or other markers along a grid made up of channels which here may be acoustical, visual or metallic. While

animate media, the instructors, are learning themselves when engaged in teaching, their learning is a byproduct and returned as input to the process of teaching students.

The foregoing description of a school may fruitfully be contrasted with that of a related but mixed, concrete system, the typical computer complex, inclusive here of hardware, software, programmers and technicians. Focusing on the non-living, equipment subsystem for the moment, it is similarly organized by information flows employing electronic markers that travel within wires or cables when sufficient energy is expended to get them moving along these channels.

The computer system, a man-made analog to the brain, has purposes fairly analagous to those of the school system, to produce and facilitate learning. The exception of course is that here the student is the bolted-down computer installation. Again, what programers and technicians learn by operating the system is subordinated to the goal of teaching the computer to "learn" ever more efficiently. So far, some amazing learning results have been obtained.

At the next higher level in the systems hierarchy, computers and schools can be seen to belong to a "suprasystem", the education system, which involves additional and complex mutual relationships. These however lie outside the immediate concern of this discussion.

(2b) Results of Intersystem Comparison

A comparison of the school and the computer points up some dramatic contrasts highly favorable to the latter. The computer

system's development displays an impressive degree of perfection and performance. Ends and means of the system, properly matched in various input-output processes, are well and operationally defined. Messages are meticulously constructed from basic information units known as "bits", each bit defining a yes-no or binary possibility that corresponds electrically to the opening or closing of a switch or "gate".

Teaching in this context simply means programing a computer, that is, decomposing incoming messages into bits and then suitably decoding or translating this information into computer language for further processing. On the output or print-out side, incidentally, the process is reversed: computer language is encoded back into the popular idiom. Circuitry and memory units are scientifically designed under physical and information theory principles for the most efficient transmission and storage of impulses, i.e. data processing. The environment of the computer system, from space, heat and humidity requirements to materials specifications, is carefully controlled, having first been engineered with cost-benefit considerations in mind.

Not so in the school, where prevailing conditions border on the primitive:

--System objectives are ill-defined, and so remain subject to vigorous debate.

--Learning processes are virtually <u>terra incognita</u>, with no solid body of principles to guide scientific applications and techniques.

--Poor communication means that what principles are discovered are by no means widely or fully applied.

--The match between marker (medium) and message is a matter of guesswork.

--Instructional messages are garbled, and rise with difficulty above distortion and random disturbances. On the other hand, information is frequently redundant.

--The elaboration of more complex messages, like the course content or the curriculum in its entirety, lacks a well-organized rationale.

--The influences of social conditions and of the academic environment on learning are largely ignored.

--Roles and decision-making in the school are locked into a traditional power structure. Change is interpreted as a threat and strongly resisted.

--Results of school activities are largely immeasurable; cost-benefit analysis is stymied.

In fairness to the school, the computer's inanimate state confers tremendous advantages on its human mentors through the precise control of variables in an artificial laboratory situation: the computer stays put while kids do not remain still even for a minute. However the computer must be taught everything that to a child comes naturally, and where the child may overlook or filter out a teacher's mistake the computer comes to a dead stop when it discovers even small programing errors.

A more deep-seated difference favoring the computer is in outlook. The typical computer facility is a no-nonsense, "straight-arrow" operation pointed at definite production goals. The school, on the other hand, still lacks a serious conception of educational processes as at least in part the equivalent of input-output relationships in a service industry. Instead, the typical school district behaves as if its chief purpose in life was to preserve a highly tenuous equilibrium between its political constituencies -- administrators, teachers, students and parents.

System-Derived Directions for Education R&D

To discover some remedies for this discrepancy in progress between computer and school, it is necessary to take another step towards formality of statement. Following system-theoretical concepts, the organizing principle for this intersystem diagnosis is the notion of a "critical subsystem" -- any process that is essential to a living system for survival.

To serve as an outline of this technique, Table A below:

a. lists these critical subsystems;

b. describes their function; and

c. identifies their location and comments on their performance in the typical school compared to a computer facility.

Fuller discussion and a derivation of possible recommendations for action follow immediately after the table which distinguishes three types of critical subsystems:

1. processors of matter-energy (m-e), which deal with physical entities;

2. processors of information, which deal with abstract entities; and

3. processors handling both matter-energy and information.

Table A

Critical Subsystems of a Viable System

Subsystem: Name	Function	Performance by: Computer	School
I. Matter-Energy Processors			
Ingestor	Carry (m-e) from environment across system boundary.	Purchasing function performed on cost-effectiveness principles.	Fair efficiency of purchasing policies.
Distributor	Transfer (m-e) whether inputs from "outside" or "inside" products of system, among components of system.		
Converter	Change inputs into more useful forms as needed for special system processes.	Production functions performed on cost-effectiveness principles.	Housekeeping, administrative and support activities carried on largely in traditional fashion.
Producer	Combine both "outside" (m-e) inputs and outputs of converter into stable form to serve such system needs as growth, repair, or transportation of products and markers.		
Storage (m-e)	Retain "deposits" of (m-e) within system for length of time required.	Business-like inventory and warehousing policies.	Tolerable efficiency in inventories.
Extruder	Dispose of (m-e) in form of products or waste across system boundary.	Distribution of output in rational fashion; waste disposal a trivial problem.	Physical output and disposal problems are trivial.

Table A (continued)

Name	Subsystem: Function	Performance by: Computer	School
Motor	Move system in part or as whole relative to environment, and rearrange parts of environment as needed.	No major problem in this area.	Transportation problems minor.
Supporter	Maintain proper distances among system components to prevent crowding.	Location of components determined by engineering principles and OR techniques.	Concept, location and layout of "school facilities" largely traditional.
II.	Information Processors		
Input transducer	Sense and receive "outside" markers, such as punch cards, tape or other terminal inputs; process them for further transmission.	Standard part of equipment design.	Needed information fails to enter system, or when brought in, remains unused.
Internal transducer	Sense and receive "inside" markers informing about significant changes within system.	Highly sensitive and reliable process controls.	Difficulty in sensing "what's going on" at administrative, faculty, student and parent levels.
Channel and net	Serve as physical routing grid for marker "traffic" within system.	Close specification of transmission characteristics. Good interpersonal information flows.	At student level, characteristics of nervous system in handling information relatively unknown. Interpersonal communication channels often clogged.
Decoder	Receive outputs from transducer for "translation" into codes (languages) "understandable" to system.	Efficient translation of instructions and other messages into computer languages.	At student level, formation of sensory stimuli into neural codes imperfectly understood.

Table A (continued)

Name	Subsystem: Function	Performance by: Computer	Performance by: School
Associator	Form information items into enduring groups, as the first stage of the "learning process".	Art of organizing information input highly developed.	Theories of learning processes lacking; teaching techniques in ritual stage.
Memory	Store information in the system as the second "stage" of the learning process.	Strategies of marker storage for convenient "warehousing" and rapid retrieval well known; sophisticated disc and tape "memories".	At student level, processes and functions of "remembering" and "forgetting" imperfectly understood. Library management traditional but seeking more advanced concepts.
Decider	Play role of system executive by receiving and transmitting all information inputs and outputs for system-wide control.	Art of giving "instructions" well advanced. Modern decision-making in force.	For lack of educational theories, teachers don't know how to "teach" or students how to "learn" efficiently; at administrative level, primitive decision rules prevail.
Encoder	Translate information from "private" system languages into codes understandable to other systems in the environment.	(Reverse of decoding process.)	(Reverse of decoding process.)
Output transducer	Send markers across system boundaries, changing their (m-e) where necessary, for transmission over channels in environment.	Print, CRT and other types of output highly engineered.	Quantity and quality of output ("learning results") suffer from inadequate information input and storage; similar conditions exist for intermediate instructor outputs.

Table (concluded)

Name	Subsystem: Function	Performance by: Computer	School
III. Processors of Matter-energy and Information			
Reproducer	Give rise to similar systems in environment.	Capability inherent in technology.	Capability inherent in system.
Boundary	Control entry and exit from system.	Open access to scientific information and new components.	High resistance to new ideas and components that may mean change.

Since both computers and schools produce services rather than engage in manufacturing (if computer manufacturing is excluded from the first system), the information processing subsystems turn out to be far more important than the matter-energy processing subsystems. The former of course have priority in the value hierarchy and thus determine the specifications of the subordinate "logistic" subsystems. It is teaching and learning which must primarily determine computer design or school layout rather than the other way around, even though engineering and architectural constraints influence what can be taught and learned in either case.

A rational system may be defined as one where the critical subsystems form an integrated whole, oriented to fulfill prime system purposes most efficiently. Failure to achieve such a rational organization, in schools, computer laboratories or whatever, may result in being stuck with a semirandom collection of semirelated processes, many irrelevant or even counterproductive to system goals.

The above cross-comparison of computers and schools pinpoints some crucial areas for action if the latter are ever to catch up. The school's "production subsystems" are not very productive, and other critical subsystems are plainly lacking in efficiency. The principal "hang up" of the school is its tragic ignorance about the very nature of its fundamental "production processes," learning and teaching. This severe and widening gap in "process information" has caused the instructional technology

applied to humans to fall ever more behind the natural-science-based computer technology. The need of the hour is a massive, intense, and wide-ranging research effort in "learning sciences," covering at least the following:

	Field	Subject of Study
1.	Neurophysiology	Behavior of central nervous system.
2.	Biochemistry	Chemical base of nervous processes.
3.	Biophysics	Physical base of nervous processes.
4.	Biomathematics	Mathematical modes of physiological processes.
5.	Bionics	Search for technological cues in plant and animal behavior.
6.	Psychology	Behavior of "normal" individuals.
7.	Psychiatry	Pathology of human behavior.
8.	Sociology	Behavior of social groups.
9.	Pedagogy	Application of teaching media.
10.	Philosophy of science	Educational objectives.
11.	Computer engineering	Design of computer complexes.
12.	Cybernetics	Simulation of self-organizing learning in computers.
13.	Systems theory	Cross-disciplinary organization of sciences.

Of course the thrust of investigation within these areas must be directed toward one question: how does the individual learn and how can that process be facilitated? Only with the aid of

a comprehensive body of theory, gathered through the patient formulation of hypotheses, experimentation and accumulation of proofs, can one begin to specify the actual behavior and components of critical educational subsystems. That is the long-run path of system development in weaponry, in space vehicles and in communication complexes, and so it must be in instructional technology.

At this stage, it seems futile to ask the computer or ITV or any other medium, no matter how "advanced", to solve the school's crisis, by a simple add-on procedure so as to obtain a "modern" education system with all components working together in harness. Such complementarity is potential -- it does not yet exist.

While the computer has proven itself as a great learner on its own ground, it cannot perform as a great teacher of humans, as envisaged by CAI and CMI, until its educational function is operationally defined. Without being told its precise role, the computer is a boob in the classroom. Small wonder that up to now no computers have been specifically designed for instructional purposes the way they have been for complex calculations, simulations, and volume routine operations in so many other fields.

(4) The Need for Continued Systems Analysis

The study of generalized systems and the formulation of systems theory is not a finished task but is breaking new ground all the time. The previous section provides only a very small sample of the domain and the power of systems theory. Consequently systems analysis, the practical utilization of theory, is not a finished tool but is constantly being updated, strengthened and modified in many salient features.

A semantic confusion arises from a double meaning of the term systems analysis but this is easily clarified. In one sense, systems analysis is like a recipe for baking a cake: a specification of all the necessary ingredients, and their order and mode of combination. In a second sense, systems analysis may mean doing the actual baking by following the instructions in the recipe. How well the cake turns out depends largely on the skill of the cook.

Extending this analogy, systems analysis may mean either the art and activity of "writing new recipes," or the art and activity of "using known recipes to bake different kinds of cakes, pastry or other dishes." The point is that systems analysis is not any "one-shot" affair -- something that is done once and finished -- but a continuing type of endeaver on a theoretical and practical plane. Moreover, just as the author of recipes may work in a model kitchen while the cook is slaving over a hot stove, the theoretical systems analyst works out his "blue prints" in some "think tank" or research laboratory while the practitioner is out "in the sticks" surveying some school district.

The gastronomic explanation of the systems approach may be stretched to deal with more complicated concoctions, like a seven-layer cake. Here the recipe consists of three "sub-recipes," that of the cake, the filling and the frosting, which must be properly prepared and combined in the right proportions, the right order, and at the right time.

Systems analysis too deals with an often complicated hierarchy of subsystems which must be identified and separated, level by level, for special treatment and later combination. In education considered as a suprasystem, system analysis may focus at a low but basic level on the classroom situation; at a somewhat higher level on the local school district; at an intermediate level on a specialized subsystem like textbook publishing; or, at a level difficult to specify, on a complex, interpenetrating subsystem like national instructional television.

There are as many potential applications of systems analysis as there are systems at different levels. The difficulty of interpretation varies from relatively simple to highly intricate, as in the design of an effective missile defense.

For the moment, the application of systems analysis in education faces its biggest obstacle in the lack of knowledge of and R&D in learning processes, as mentioned before. Going back to the kitchen analogy, the situation resembles that where a recipe for bread calls for a certain amount of flour, and as it happens the cupboard is bare, the grocer is out of it, the miller

has exhausted his supply, and the farmer is facing a crop failure. The outlook for genuine bread under those circumstances is extremely dim until the problem of flour supply can be straightened out.

There is no magic in a recipe as such, nor can there be in systems analysis, when some basic ingredients are missing. But knowing exactly which ingredients are lacking and why may lead to asking the right questions, and from there straight to action for prompt procurement. In that respect, theoretical systems analysis is able to put educational development on the right track, principally be organizing its R&D effort and by pointing it in the right direction. If the will and the funds are there, the job can be done.