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ABSTRACT

This paper uses the conceptual framework of cybernetics to understand why learning information systems such as the "Accelerated Reader" work so successfully, and to examine how this simple yet incisive concept can be used to accelerate learning at every level and in all disciplines. The first section, "Basic Concepts," discusses the cybernetic analytical framework; feedback, time series, memory, and forgetting; and information theory. The second section of the paper, "Issues in Applying Cybernetics to Human Systems and Education," addresses translating feedback control terminology to common terminology; positive alignment of human purposes; importance of information and measurement in human systems; characteristics of "good" measurement; the role of technology; a cybernetic framework for enhancing motivation; and hostility toward objective measurement. The third section, "A Cybernetic Analysis of Three Systems," discusses economic systems, games and sports, and the Accelerated Reader program. The paper concludes that a cybernetic understanding of human systems in general, and specifically of educational systems, can provide important insights that hold out the possibility of improvement. (RS)

Learning Information Systems

THEORETICAL FOUNDATIONS

Paper given at the National Reading Research Center Conference, *"Literacy and Technology for the 21st Century"* Atlanta, Georgia
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THE INSTITUTE for ACADEMIC EXCELLENCE

An Institute for Academic Excellence Monograph

The New Technology of Learning Information Systems: Theoretical Foundations

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Foreword

The concept of the learning information system I present in this paper represents a paradigm shift in our thinking about learning, schools and the role of teachers. To a great extent, the billions of dollars spent on educational technology have been directed at fixing some presumed deficit in our teachers—or to replacing teachers all together. Implied in this approach is the assumption that the problem with education is an instructional problem.

With very few exceptions, educational technology has failed to deliver on its promise to transform learning, despite the vast resources devoted to it. One of those rare exceptions has been the Accelerated Reader reading information system. Rather than starting from the assumption that teachers needed fixing, the design of the Accelerated Reader presumes that teachers are capable of greatly accelerating the learning of their students if only they are provided with timely and accurate information about student learning tasks. This important difference in philosophy has resulted in the Accelerated Reader becoming the leading reading technology in schools today, used in more than 27,000 elementary and secondary schools nationwide. The purpose of this monograph is to use the conceptual framework of cybernetics to understand why learning information systems such as the Accelerated Reader work so successfully, and to examine how this simple yet incisive concept can be used to accelerate learning at every level and in all disciplines.

The recent introduction of the S.T.A.R. computer-adaptive reading test is the result of our own attempts to create learning information systems based on cybernetic principles. AR manages information at the task level, providing students and teachers with feedback on reading task completion and performance. In turn, S.T.A.R. provides a classroom learning assessment system that provides information to teachers on reading growth—information that can then be used to evaluate and adjust student learning tasks. The combined use of AR and S.T.A.R. provides nested, aligned feedback loops that help teachers and students connect learning tasks with learning achievement. Unlike other standardized reading tests, S.T.A.R. is designed, not as a way to abuse teachers, but as a source of vital information to help them do their jobs more effectively.

Most educators are not familiar with the science of cybernetics. We hope that the publication of this paper will help many educators understand the importance of this powerful theoretical foundation for classroom learning information systems. I have found most teachers to be practical people who are somewhat disinterested in theory; but I believe the impressive results AR has achieved in thousands of classrooms will encourage them to discover how the software's theoretical basis can help them revolutionize their teaching, and in turn create tremendous benefits for their students and for our entire society.

Terrance D. Paul

Madison, January 1997

The New Technology of Learning Information Systems: Theoretical Foundations‡

By Terrance D. Paul

Introduction

In the early forties, Norbert Wiener, a renowned mathematician and something of a Renaissance man, called together fifteen scientists in various fields including mathematics, physics, biology, economics, and sociology to discuss a type of problem that cuts across all disciplines. The interdisciplinary problem that interested him was the problem of control.

In 1948, with the publication of Wiener's book, "Cybernetics," a new scicnce was born, the science of control and communication in purposeful systems[1]. Although little known outside the realms of technology, cybernetics has had a profound effect on our world. Many important developments in computer science and communications technology are based on cybernetic theory.

In spite of the technological successes of cybernetics, it has not had much impact on the social sciences or education[2]. This is unfortunate. This paper will attempt to demonstrate that cybernetics provides a powerful analytical framework which is potentially just as useful to the social sciences as the natural sciences.

I begin by describing the basic concepts of the cybernetic analytical framework. While many cybernetic theorems and proofs are highly mathematical, the basic concepts are not difficult to understand; and these concepts provide a useful point of vicw and a way of thinking about the world. The second section explores the primary issues in expanding cybernetics to human systems and education. The last section demonstrates the usefulness of cybernetics through an analysis of three systems, including the Accelerated Reader® technology-based literacy program.

‡ Paper originally presented as *A Cybernetic Approach to Motivation and Improvement of Human Systems, with an Emphasis on Schools, Technology and Literacy.*

I. Basic Concepts

The Cybernetic Analytical Framework[3]

Cybernetics is concerned with the control of purposeful systems. It is the concept of purpose that most distinguishes cybernetic from non-cybernetic systems. It is control that makes it possible for a system to accomplish its purposes. Control and purpose are linked. A system which has no purpose has no need for control. The cybernetic world is composed of an awesome network of nested and interrelated purposeful systems, ranging from the universe itself, to planets, ecosystems, cultures, tribes, schools, human beings, circulatory systems, heart, muscle, molecule, and atom. One may well ask what the "purpose" of a solar system or an atom might be. For the cybernetician, the purpose of a system is defined by its output. For example, the purpose of the universe could be cybernetically described as the creation of stars, an atom as a machine to rotate electrons about its nucleus, a human being as a system to survive by passing its genes to the next generation. In other words, cybernetics avoids the metaphysical issues inherent in the concept of purpose and focuses on that part of reality that one can sense and measure.

Another attribute of cybernetic systems is they tend to be exceedingly complex and probabilistic such that their inner workings are unknown. In as much as this complexity makes causation indeterminable, cybernetics is not terribly concerned with causation. Systems are studied by looking at inputs and outputs and building models rather than dissecting the system or speculating about its inner workings.

Another aspect of cybernetic systems is they are homeostats. This is a corollary of the idea of purposeful systems. A homeostat is a control device for holding some variable constant. A room temperature control and an automobile cruise control are homeostats. The unique characteristic of a cybernetic homeostatic system is that it is self-regulating and adaptive. It responds to exogenous variables and, through iterative cycles, dynamically reestablishes homeostasis at the desired set-point.

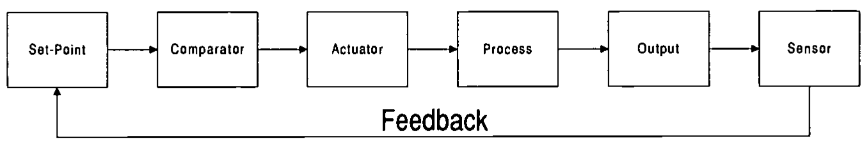
In summary, systems which are the focus of cybernetic theory are first and foremost purposeful. Other characteristics of such systems are they are dynamic, interactive, iterative, probabilistic, homeostatic, self-regulating, adaptive, and highly complex. Such systems are also interrelated and nested within each other in levels of increasing complexity. Interestingly, there are an infinite number of systems like this. Human beings and biological organisms of every type satisfy this criteria as do, at some level, virtually all physical systems.

Feedback, Time Series, Memory, and Forgetting

While the most important characteristic of cybernetic systems is purposefulness, the most important feature of control is feedback. Feedback is what allows a cybernetic system to adapt and enables complex systems to learn. The best way to understand feedback is to first diagram a general form of control and then to illustrate with a diagram and an example. One quickly realizes that feedback is ubiquitous.

A control has six basic stages: 1) a set-point, 2) comparator, 3) actuator, 4) process, 5) output, and 6) sensor.

Figure 1
Generalized Feedback Control Diagram[4]



Feedback describes the information flow by which the output is sensed or measured and compared to the desired set-point. For example, consider the home thermostat. Let's assume the thermostat is set at 70 degrees, and that the sensor measures the room temperature to be 60 degrees. This information is compared to the desired set-point and the information is sent on to the actuator which turns on the furnace. The operation of the furnace is the process or value creation stage, and is the stage which satisfies the systems purposes. The output is heat. The feedback consists of the sensor and comparator stages and the information flowing between the stages. Homeostasis is reached when the temperature is maintained at 70 degrees. Note that the control system actually forms a loop. Because of this loop feature, a control utilizing feedback is sometimes alternatively called a feedback loop, closed-loop feedback control, control loop, or even simply loop. Also, closed-loop is the opposite of open-loop. When it is said a system is running open-loop, it means the system is out of control.

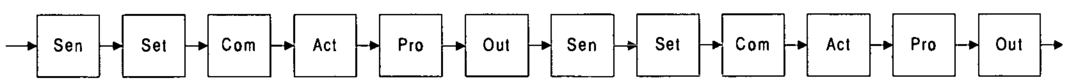
Cybernetic systems employ both negative and positive feedback. What is meant by negative feedback is that the feedback tends to oppose what the system is already doing; the feedback constrains the output. Negative feedback is a corollary to the idea of purposeful systems. Negative feedback says "too little" or "too much." Positive feedback, on the other hand, which says simply, "keep it up," may be unnecessary feedback information in many purposeful systems. Many controls only have negative feedback. Although negative feedback is essential for all purposeful systems, positive feedback is essential for human systems and other complex probabilistic systems. Positive feedback is critical information, because it enhances the ability of the system to predict. In human beings, it shapes beliefs and attitudes almost as much as negative feedback.

Another aspect of feedback control is response time, which is a measure of how quickly the studied system achieves homeostasis. The response time for a human to catch a ball is quite fast, to maintain constant blood temperature quite a bit slower. The response rate matches the needs of the system to accomplish its purpose.

One last point to make about feedback is that while it is a wonderfully useful abstract, it is an illusion. Time does not go backwards. In reality there is never anything to feedback to. Information moves only forward in time. On the surface this may seem to be an unimportant distinction; after all, most of us never thought about time going backwards[5]. But the distinction is critical. The information flow is always moving forward in time, continuously through each stage with endless repeating stages. In other words, a more correct way of diagraming the feedback control loop is shown below:

Figure 2

Forward in Time Feedback Control Diagram



Sen = Sensor Com = Comparator Pro = Process

Set = Set-Point Act = Actuator Out = Output

When the control diagram is laid out this way, it suggests a very important feature of cybernetic controls. Because information moves forward in time, a dynamic system must remember and predict in order to adapt. The set-point must be remembered and compared to the present situation. At the third stage, the actuator stage, a decision has to be made. Do we need to turn on the furnace or turn off the furnace? The decision in turn requires a prediction: Will turning on the furnace increase or decrease heat? Of course in mechanical systems this kind of memory and prediction are stored in the design of the hardware. In extremely complex and probabilistic systems—and humans may be the most complex of all—memory and prediction become much more problematic. For humans, one of the most important predictions is, "Do I believe if I pursue this process or activity, it will increase my status?" In the cybernetic model, the usefulness of human beliefs is that they aid in prediction.

Not only are memory and prediction important elements of control, so is forgetting. Only through forgetting is adaptation possible. To adjust the temperature setting for the room, the control must "forget" the previous setting. While memory is an essential feature of any purposeful system, forgetting is essential for adaptation and survival. Biologists have discovered that the human brain is divided physically into short-term and long-term memory locations and these are critical to the process of adapting to new conditions; short-term memory and forgetting for fast adaptation, long-term memory for slow adaptation[6]. From a cybernetic standpoint, genes are a long-term memory mechanism. Genes hold the memory for the most important and unchanging elements of a species. But through a process of genetic mutation, the gene pool slowly changes—it forgets old instructions and learns new ones. If it didn't, we would still be amoebae!

Information Theory

While feedback (or feedforward in time, depending on how you draw the diagram) is the key element of control, the glue and energy for the control network comes from the information flows that link the various parts. Information theory is an important tool of cybernetics[7].

The first principle of information theory is that information must be differentiated from background noise in order to be useful. The more the differentiation, the higher the information content of the message. Undifferentiated information is an oxymoron; it is not information at all, but simply noise. The higher the information content in a system, the more organized, the more regular and predictable the output, and the better the system will be at accomplishing its purposes. A system producing an output with high variance is a system that has low information content and high noise content. Another name for high noise content is entropy. Entropy is a term that cyberneticians have borrowed from thermodynamics. It describes a state in which the energy in the system is uniform. There is no differentiation and therefore no information when maximum entropy is reached. Using the example of the home thermostat again, if you remove the tempcrature sensor from the system, there is no information, and the system goes out of control; it's running open-loop. There is no telling what temperature will be maintained. Compare this to the situation of connecting the sensor for a brief period each hour. The increased feedback would help the system keep the room temperature somewhat more predictable, but it still would not be maintained as precisely compared to a full-time sensor. A full-time sensor maximizes information, maximizes control, minimizes variance, and minimizes entropy.

Cybernetics is very concerned with the sources of entropy. It is entropy or the lack of information which reduces the ability of the system to accomplish its purposes. In a sense, then, there are always two systems with which cybernetics is concerned: the system which creates useful information, and the system which creates noise. Sometimes cyberneticians will refer to the entropy system or noise-creating system as the machine within the machine that works against the purpose of the machine.

John Goodlad, in his classic study, *A Place Called School*, is clearly describing a condition of entropy when he summarizes data from 1,000 classrooms[8]:

> ". . . There is a paucity of praise and correction of students' performance, as well as of teacher guidance in how to do better next time. Teachers tend not to respond in overtly positive or negative ways to the work students do. And our impression is that classes generally tend not to be strongly positive or strongly negative places to be. Enthusiasm and joy and anger are kept under control."(p. 124)

> "If positive relations with teachers in classrooms are related to student satisfaction in school and corrective feedback is related to student achievement, then it becomes imperative to seek school conditions likely to maximize both. The never-ending movement of students and teachers from class to class appears not conducive to teachers and students getting to know one another, let alone to their establishing a stable, mutually supportive relationship. Indeed, it would appear to foster the casualness and neutrality in human relations we observed to characterize so many of the classrooms in our sample." (p. 112-113)

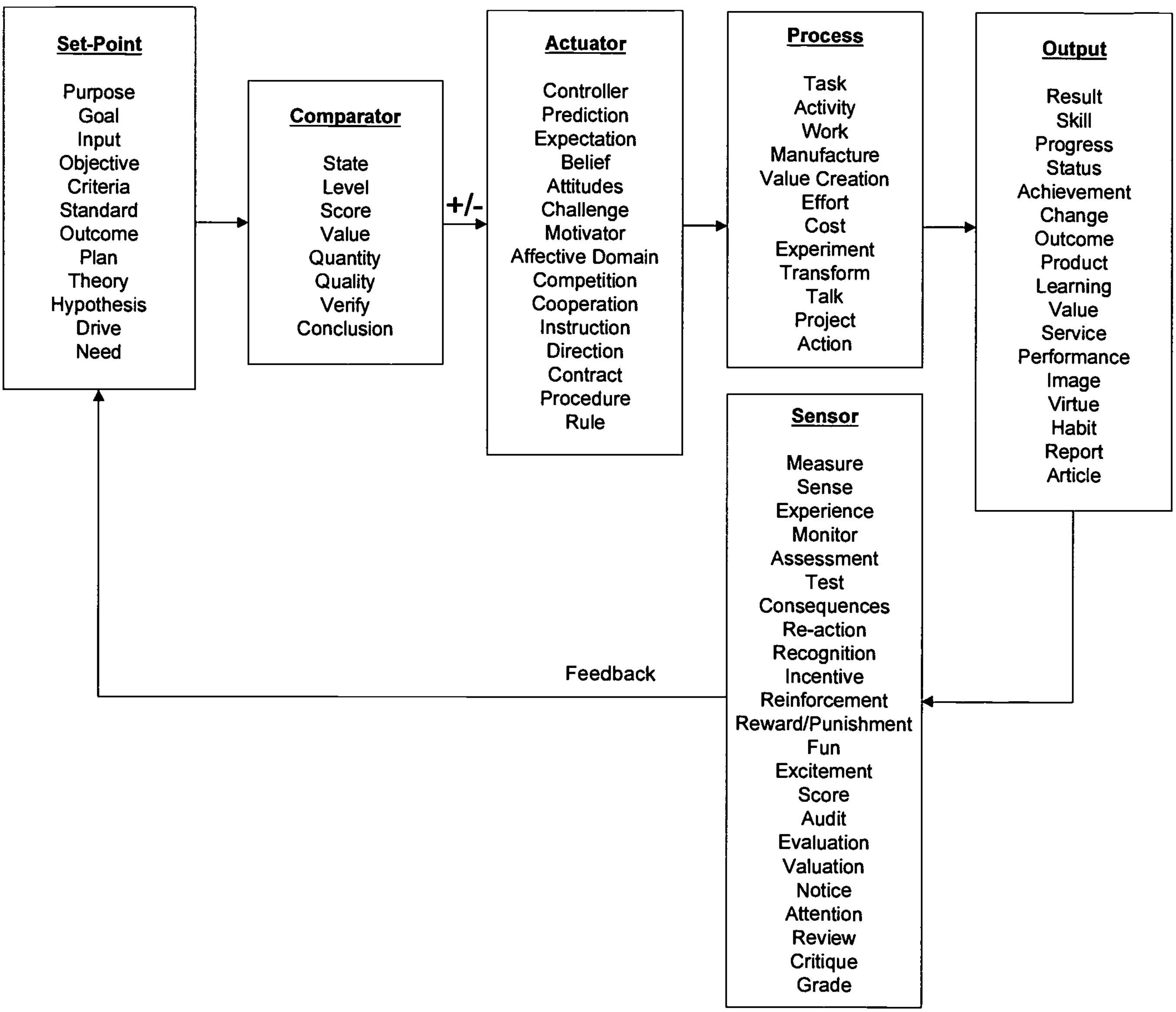
II. Issues in Applying Cybernetics to Human Systems and Education

Translating Feedback Control Terminology to Common Terminology

The first step in making cybernetics more applicable to humans and human organizations is to understand how the terminology used for the six stages of control (set-point, comparator, actuator, process, output, and sensor) applies to the elements of perception, thought, and work—in effect, to translate cybernetic principles into more commonly understood terms. As we will see, this project quickly becomes a semantic problem; the correct stage for any given term will change depending on the meaning of that term at that stage—"value," for instance, undergoes a subtle, but important, change from the comparator stage to the output stage. As well, any of these given stages may also involve its own cybernetic system; the activity of the controller at the actuator stage may involve its own cybernetic control loop, for instance. Figure 3 translates the cybernetic stages into the more customary terminology of human activity.

Figure 3

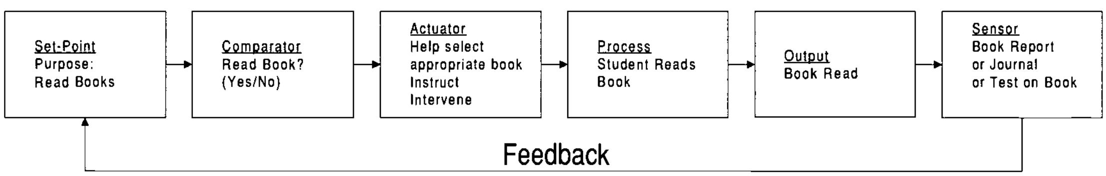
Closed-Loop Feedback Control Expanded Terminology



Positive Alignment of Human Purposes

One of the most obvious educational applications for cybernetics is to optimize tasks or learning activities such as textbook reading, working math problems, writing, completing work sheets and projects, and literature-based reading. Basically, the objective is to bring the task under control so as to maximize the learning rate by increasing the quantity, quality, and level of effort. Shown below is how a task loop for literature-based reading might be labeled:

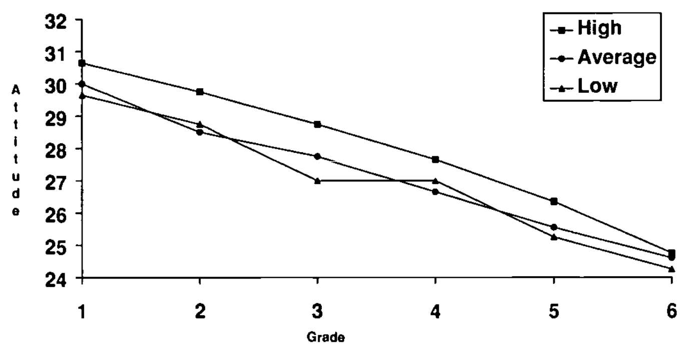
Figure 4
Control Loop for Literature-Based Reading
(Instruction or Task Loop)



The task loop as diagramed is an excellent example of cybernetically-sound control. One might think that this is all there is to it. There is a feedback loop in place; entropy and variance should be low. Yet while our diagram appears to satisfy the cybernetic requirements of a closed-loop system, it ignores the fact that in the actual classroom, this system has no reality in and of itself. It can only function through the interrelated processes of at least two other discrete "systems"—the student and the teacher. For this educational system to produce its desired output, people must serve as its agents of memory, valuation and control, and these people may desire outputs at some degree of variance from that of the control loop diagramed here. The point is that good instructional design will always involve many interrelated cybernetic systems: the instructional loop, the student and teacher loops, home loops, peer loops, community loops, and more. To maximize educational output, all of these systems must be positively aligned and coupled by information links so that an increase in the desired instructional activity also serves the purposes of everyone involved: the student, teacher, parent, and peer. In other words, the purposes of the task loop must be aligned with the purposes of the student and all the people important to the student[9]. An example of an excellent cybernetic system where positive alignment of the social environment occurs is sports. If a kid scores a goal or makes a basket, the experience supports the student's purposes, and the purposes of the coach, parent, and peer (the sports analogy will be expanded on in the next section).

What are the effects of positive and negative alignment in a classroom situation? I believe Michael McKenna's study, *Children's Attitudes Toward Reading: A National Survey,* provides us with a good illustration of both types of alignment. McKenna found that children's attitudes towards textbook reading steadily dropped from first grade through sixth grade[10]. What is most interesting is that the drop was almost exactly the same regardless of whether the students were of high, low, or average reading ability. See Figure 5.

Figure 5
Attitude Toward Academic Reading for Students With High, Average, and Low Ability Across Grades

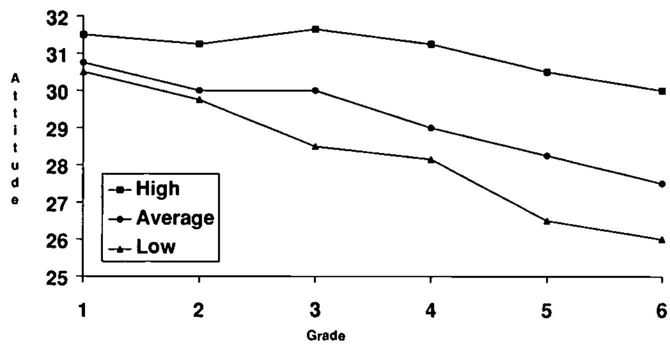


This is anomalous to what one would expect. We would expect high-ability students to find academic reading a more fulfilling and less frustrating activity than low-ability students; high-ability students, therefore, should tend over time to exhibit more positive attitudes toward reading. But this does not happen. All three groups converge in attitudes over time. What this data strongly suggests it that there is negative alignment between the academic reading loop and the student-peer loop for all ability groups, and that this negative alignment overwhelms any positive feedback effects related to ability.

McKenna also looked at recreational reading (tradebook reading) attitudes. In this case, although reading attitudes decreased for all ability groups, there was significant divergence in reading attitudes over time. See Figure 6 on next page.

This suggests there is a difference between the alignment of purposes for recreational reading versus academic reading. There are many possible explanations for this. Perhaps the most important is that typically, in the case of recreational reading, students have some choice in what they read, and are free to read what interests them. This naturally will cause a better alignment between the student's purposes and the instructional purpose.

Figure 6
Attitude Toward Recreational Reading for Students With High, Average, and Low Ability Across Grades



Cybernetics is about purposeful interrelated systems. A primary insight that arises from this way of thinking about instructional design is that positive alignment of purposes is critical to the successful functioning of an educational system. The lack of positive alignment is likely to be one of the largest sources of entropy, particularly during adolescence, when students are increasingly motivated by purposes that either conflict with or are antithetical to those of the instructional system. This is the elusive machine within the machine that works against the purpose of the machine.

Importance of Information and Measurement in Human Systems

If a tree falls, and no one hears it, does it make a sound? From a cybernetic perspective, the answer is clearly "No;" if you can't sense or measure it, it didn't happen. Unless a phenomenon is sensed and differentiated by the system, it is utterly irrelevant to the system, and might as well not have occurred. The purpose of a system is defined by its output; without effective measurement and evaluation of output, the system cannot regulate itself—it runs open-loop. When educators say tests drive curriculum, they are confirming a major thesis of cybernetics.

This is not to say measurement causes objectives, but only that an objective that is not measured will, over time, have no impact on the output of the system. Another way of expressing this thought is to say that while the establishment of objectives is perhaps the first step in planning, it is largely irrelevant unless one also measures the output. Consider what would happen in the game of basketball if a black curtain was put in front of the basket. We would know if the ball flies over the curtain, but not if it actually goes in the basket. The purpose of the game and game behavior will then quickly become directed at getting the ball over the curtain. Of course, we may continue to say the objective is to make baskets, but the language and beliefs about the game would be belied by what is actually sensed or measured. Cybernetically, objectives or purposes or intentions which are not measured are illusions.

In the same way, the sense and measurement stage of the control defines the impact and effectiveness of all other stages of control, the comparator, actuator, process, and output. The cybernetic answer to whether there can be useful beliefs, motivation, or attitudes without measurement is the same as whether there can be sound without hearing. Without measurement, there is no information, no purpose, no motivation, and no control.

Characteristics of "Good" Measurement

We have said that the first concept of information theory is differentiation. Good measurement differentiates. Undifferentiated information is simply noise; the more we can say this is different from that, the better the system will operate. For example, a measured ranking of a student's reading comprehension at the 92nd percentile is more highly differentiated, and therefore contains more information, than saying the student is in the top 25 percent.

The search for differentiation, then, defines the desirability of certain characteristics of measurement. We would like measurements to be valid and reliable; the statistic should measure what it purports to measure[11]. For example, while a person's height and weight are highly correlated, it is more direct, valid, and reliable to measure height in inches than pounds.

But differentiation is not sufficient. Good measurement must also be useful and necessary to the accomplishment of the systems purposes. Information that is not useful or not used is no different than undifferentiated information; it is simply noise. Any measurement which on balance improves the ability of the system to achieve its purposes is good measurement; all the rest is noise. In other words, good measurement incorporates the law of parsimony[12].

In order to enhance a system's ability to accomplish its purposes, we would like to compare outcomes of different systems to one another, or to compare the output of one system at different times or under variable conditions. The ability to differentiate on the basis of comparable output is critical to successful self-regulation. This requirement for comparability would lead us to prefer objective measurements to subjective evaluations. This isn't to say subjective evaluations are wrong or useless, but simply that their noncomparability limits their differentiation and tends to give them a higher noise content. Often, subjective measurements can be made more objective through a standardized process of recording one's observations. Marie Clay, who developed Reading Recovery, uses a documentation scheme which makes the assessment both more systematic and objective[13]. It may, in fact, be Clay's documentation system which explains some of Reading Recovery's success compared to other one-on-one tutoring techniques[14].

Of course, a problem occurs when it is difficult or impossible to measure something directly. Intelligence is a good example of something which cannot be measured directly. In such a situation, causation and validity are always an issue. Sometimes it is actually better in terms of validity and reliability to measure indirectly. One characteristic which seems to be difficult, if not impossible, to measure directly is higher-order thinking skills. Performance assessment schemes, often suggested as a preferable measure of higher-order skills, have had to grapple with issues of reliability, validity, and bias[15]. A more valid assessment of higher-order thinking skills might be to create a comparable indirect measurement, perhaps by measuring a trait associated with higher order thought. For example, if we accept the constructivist theory that students construct the meaning of vocabulary from seeing and hearing words in meaningful contexts[16], then student vocabulary becomes a "marker" for the higher-order process of making meaning from text. A standardized multiple-choice vocabulary test, then, would provide an indirect means of measuring the development of higher-order skills that cannot be directly measured in themselves. Given its more differentiated nature, such an indirect measurement may well be a more reliable and valid measure of verbal higher-order skills than a performance assessment.

A problem of similar type is measurement of time on task. Of course, it is relatively easy to measure time, but it is not easy to measure mentally-engaged time, and it is only mentally-engaged time that is relevant to learning[17]. For example, if the objective is to have students spend time working math problems, it is better to measure the number of math problems worked (i.e., the output) versus time elapsed. The number of problems worked tells us a great deal about mental engagement; elapsed time tells us very little. A measurement of elapsed time on task can only be useful in the context of measured output; once again, the concrete indirect measurement is more useful for the purposes of system self-regulation.

Another issue clarified by the need for differentiation is the relative value of criterion-referenced tests versus norm-referenced tests. From a cybernetic standpoint, both have value. It is useful to know that state or district standards are being met; but from the standpoint of self-regulation for maximum output, it is also critical to have comparative, normative information such as whether the state or district finished first or last in the region. Usually, criterion-referenced tests do not replace the need or usefulness of norm-referenced information. Cybernetically, all information is in a sense normative, because information is only useful if it differentiates.

Our observation of entropy in the kind of information-poor school setting Goodlad describes attests to the critical nature of the information feedback loop in educational systems. Another, more positive example can be drawn from research in one-on-one tutoring. Almost all types of one-on-one tutoring demonstrate what Benjamin Bloom calls the two sigma effect of tutoring; learning typically occurs at a rate which is two standard deviations faster than the control[18]. Our cybernetic perspective would lead us to understand this effectiveness as a result of well-aligned, information-rich feedback loops. In one-on-one tutoring, there is a tremendous exchange of information and feedback incorporating a wealth of verbal and non-verbal communication between tutee and tutor. The assessment and feedback occurs instantaneously, and, as in any system, the more frequent the measurement, the faster the response rate of the loop. Also, frequent measurement and feedback significantly enhances prediction. The link between time on task and results will be much more obvious and a significant help to development of metacognition[19].

Our search for useful measurements takes place in the context of highly-complex systems in which it is difficult to exhaust the possible sources of vital feedback. To return to our tutoring example, impromptu information can be irreplaceable. For example, if the tutor wants to know why the student is having difficulty reading a book about airplanes, the student might respond that he hates stories about airplanes. This is information that could never be teased out of a test result, although the test result might be suggestive of the need to ask the question in the first place[20]. Rarely does one type or method of measurement replace or eliminate the need for other methods.

In summary, the tutor-student relationship provides a wonderful example of an educational system based on sound cybernetic principles; its demonstrated success suggests the potential value of examining other educational systems in light of these principles. Practically, however, the resource-intensive nature of one-on-one tutoring sessions makes it unlikely that they will ever become the primary pedagogical approach in schools. What is needed are methods to increase the effectiveness of information loops in the typical classroom which can approach one-on-one tutoring. I suggest that the answer to this lies in understanding the proper role of measurement in education and in the use of technology.

The Role of Technology

So far technology has had little real impact on daily life in the classroom, for all the billions of dollars that have been invested in it[21]. One possible cybernetic explanation is that educational technology has been negatively aligned with student or teacher purposes. The key to making the revolutionary benefits of technology truly available to students and educators is to positively align the purposes of these human systems with those of the electronic ones.

Information technology, the very technology which cybernetics helped create, makes the educational revolution a possibility. Computers greatly reduce the cost of collecting, storing, organizing, and distributing information, and information is the energy for the control of purposeful systems. However, as my previous analysis suggests, the main opportunity for the application of technology is in improving measurement and feedback of results. This, in turn, leads to a situation in which students can become more self-directed in their educational pursuits because both the student and teacher will have more information and control. In essence, increased student and teacher control leads to higher effectiveness and the potential for more individual freedom. This effect is, I believe, clearly demonstrated by the success of the Accelerated Reader technology-based literacy program, which I describe in the final section of this paper.

A Cybernetic Framework for Enhancing Motivation

The cybernetic model suggests a certain point of view regarding human motivation, a view consistent with observations from the behavioralist, cognitive, and evolutionary psychology camps, and therefore somewhat difficult to categorize. On one hand, it favors a cognitive approach because cybernetics is fundamentally about purposeful systems, and suggests explanations as to how information, both external (sense, experience, measurement) and internal (memory, belief, attitude), impacts the behavior of the system. Also, the cybernetic feedback control model highlights the importance of prediction. This concept, in turn, seems to parallel cognitive expectancy-value motivation theory. On the other hand, because cybernetics supports incentive motivation theories and tends to avoid issues of causation, it contains similarities to the behavioralist approach. Part of the problem, of course, in trying to classify the cybernetic perspective is that most motivational theories overlap and many apparent differences are semantic.

While most motivational models provide some explanatory value, the widely-accepted cognitive achievement motivation model proposed by Ausubel seems particularly useful and consistent with cybernetic theory[22]. Ausubel's application of this model to education is parsimonious in that it assumes only three drives: cognitive, affiliative, and ego-enhancement; yet it does much to explain the primary motivational problem in education, the tremendous drop off of learning motivation that occurs as students approach adolescence. The achievement motivation model also seems to be relatively consistent with the latest developments in evolutionary psychology[23].

Although cybernetics does not suggest a complete motivation theory, it does provide useful insight. What cybernetics brings to the table is a clear conception of control as fundamental to achievement of purpose. This conception, in turn, suggests certain conditions precedent to motivation. In other words, cybernetics addresses the elements that enable motivation.

From a cybernetic standpoint, information is the energy that permits the system to produce and self-regulate according to its purposes, and is therefore the energy that fuels motivation. Increase information, and you have the potential for increased motivation. What cybernetics highlights, then, is the need to increase the amount of information by improving the measurement of results.

Although measurement of results and feedback are the most important ingredients to improving motivation, they are by no means the only elements suggested by the cybernetic analysis. Any kind of information which improves prediction will also enhance motivation. This would include things like clearly stated objectives, articulate instruction, clear instructional materials, etc. Prediction is also improved by information enhancement as a result of increasing the frequency of feedback, repetition, and a structured, familiar environment.

While improving information through measurement and feedback is the most important step to improving motivation, the next most important step suggested by the cybernetic model is positive alignment of purposes. An improvement in the accomplishment of the task or process should be positively linked to the satisfaction of human purposes. If one accepts that achievement is an important motivator, then humans will wish to control for achievement; from the cybernetic perspective, then, achievement is the output of human systems. However, achievement in this sense means something more than just mundane activity. It means accomplishing challenging things. Achievement, in other words, includes the idea of challenge. Challenge is implicit in the three components of achievement motivation: the cognitive, affiliative, and ego-enhancement drives. The cognitive drive is the drive to know the unknown, the new and challenging. Ego-enhancement requires one to stand out, to do something challenging for which one is recognized. One can also see in this idea the value of competition as a means of creating challenge as well as a means of satisfying the affiliation drive. Therefore, given the importance of achievement to human motivation, an important mechanism to positive alignment is challenge and high expectations. Also, challenge plays another important role, that of keeping students working at the edge of what they know, further accelerating learning.

High expectations and challenge have long been recognized as an important element in effective schools. The cybernetic analysis reinforces its importance. Challenge improves motivation, creates positive alignment, and accelerates learning. In summary, one might say that the cybernetic model of motivation I propose consists of three elements: information, alignment, and challenge.

Hostility Toward Objective Measurement

A discussion of motivation and measurement is not complete without recognizing the natural hostility to the very idea of measuring humans or anything related to humans. There have been many negative uses of measurement[24]. It only tends to slightly ameliorate the concern to know that many of the negative uses are essentially situations in which there is no positive alignment of purposes.

Even beyond the problem of the negative use of information, there are many forces and arguments lined up against measurement. Negative feedback can contribute to cognitive dissonance, to which we often respond by attempting to restrict our exposure to the source of negative information—the "kill the messenger" effect. To encourage a more productive response to cognitive dissonance, attention needs to be focused on reducing the threatening aspects of feedback information. In this regard, impersonal objective measurement is more likely to be accepted than personal subjective information. It also helps if the consequences of failure are learning instead of punishment.

Second, certain motivational theories claim measurement inevitably reduces motivation. Self-esteem theories fall in this category. In such theories, high self-esteem is believed to be necessary for learning motivation; all negative feedback is believed to reduce self-esteem and all positive feedback is believed to increase it. Despite the current popularity of these beliefs, there is little solid evidence to support them[25].

Much of the popular appeal of certain types of motivation theory appear to be grounded in a kind of metaphysical moralism. Examples include theories which suggest normative information is inherently wrong because comparing students denies their essential nature as self-actualizing individuals. Comparison suggests external sources of control, which for those who accept these beliefs is tantamount to coercion. From this they conclude that any form of competition, any objective measurement linked to positive or negative consequences, rewards, and even praise, are morally wrong because the control of one person by another is morally wrong—regardless of who is in control or to what purpose[26]. As Lisa Delpit and others have observed, however, we cannot eliminate the power dynamics in a classroom. If we pretend to do so by reducing control (by diluting objective standards, for instance), we simply make it that much harder for disadvantaged children to understand what the system expects of them, what it will reward them for, and how they can use it to achieve their goals[27].

A cybernetic perspective demands that we confront the purposeful nature of human systems, and accept that the achievement of our purposes, even freedom, requires control. Also, some of the hostility to a scientific approach can be reduced by assuring that measurements, normative information, competition, and rewards are positively aligned to human purposes. This positive alignment of purposes is not only a scientific concept that leads to increased motivation and enhances the effectiveness of control— it can also be viewed as a moral imperative.

III. A Cybernetic Analysis of Three Systems

Economic Systems

Economic systems are an example of cybernetic social systems and illustrate the importance of information and measurement for efficiency, positive alignment, and motivation. From a societal point of view, the purpose of an economic system is everywhere the same: to produce goods and services to satisfy human wants and needs. There are essentially two types of economic systems: the command economy and the free economy. While virtually all economies incorporate characteristics of both, in general any given economy will tend to be dominated by the attributes of one of these opposing types.

There is a vast difference between the amount of information available in a command economy as opposed to a free economy. Because communication and measurement in a free economy is accomplished primarily through the price mechanism, free economies tend to have a much higher information content. Economists have long recognized the huge information content of price. Prices have all the characteristics suggested earlier of good measurements. The price of a good or service reflects the cost of production and the value to the customer. Prices also communicate predictions of the future. If demand or supply is expected to change, this will be reflected in the price. Higher prices are the feedback control signal to suppliers to produce more; lower prices call for less production. Prices are very precise measures of customer value and are, therefore, a reflection of human purposes. Prices allow comparisons and precise differentiation between goods and services over time and from place to place. A single price for a single item is an infinitely complex summation of costs and values. Price contains so much information that no human, even one equipped with the most powerful computer, can predict what the free market price will be. It is the same problem meteorologists have in predicting the exact temperature of the air over a certain spot on the earth five days hence, or the problem the investor has in picking a stock.

Consistent with cybernetic theory, we can readily observe that anything which tends to reduce the information content of prices will reduce efficiency and reduce the ability of both consumers and producers to accomplish their purposes.

A good example is what happens with price inflation or deflation; both result in a huge loss of information. Carried to the extreme both conditions lead to economic collapse. When prices are no longer stable, they no longer are predictable or comparable. No one is willing to invest and save. Price as a measuring stick becomes worthless and the economic system is reduced to a barter economy. The result of high inflation or deflation, in other words, is entropy.

Compared to a free economy, a command economy is relatively information poor. Prices do not direct economic activity; this is the intended role of the economic plan, which is a partly political, partly economic document reflecting the knowledge of relatively few consumers and producers. As a result, the information flow between consumers and producers is inhibited, leading to negative alignment of purposes that manifests itself in the waste and scarcity common to these economies. Within the command economy, information is in short supply, and therefore, extremely valuable. The people who are rich in a command economy are those who control or who have access to information—in other words, those with political clout. A typical trait of command economies is a listlessness and a kind of stagnation caused by a lack of incentives and motivation. On the other hand, the incentives, enthusiasm, and motivation for political and informational power is quite high. From a cybernetic standpoint, our Bill of Rights guaranteeing freedom of assembly, press, and speech is as much an economic manifesto as it is a political manifesto. Such political rights greatly increase the amount of information, and thereby increase feedback, control, motivation, and the ability of citizens to accomplish their own purposes as they may define them.

Games and Sports

Next to economic systems, probably the best example of a cybernetic social system is sports. Like it or hate it, sports is a worldwide intercultural intergenerational addiction. We must begin our cybernetic analysis by asking what the purpose of sports might be. Positively, it can be viewed as a system to keep people fit, and for development of teamwork. Such historical examples as Spartan culture demonstrate the important link between these values of sports and the survival of the polis. As individual athletes, our purposes may be achievement of fame and fortune. Others might argue the purpose is to teach moral values; we think of the Olympic ideal of good sportsmanship and fair play. Finally, perhaps it is a way of diverting our aggressive, competitive urges into something more positive than maiming and killing.

Maligned or not, sports have always been held up as an example of a highly motivational activity. One is likely to find a sports analogy related to motivation or teamwork in almost every after-dinner speech. Given the highly motivational characteristics of sports, it is not surprising that sports are an excellent example of the implementation of cybernetic concepts of closed-loop feedback control, positive alignment of purpose, and challenge.

All games and sports implement closed-loop feedback control. In sports, feedback is typically instantaneous; the shot goes in, the touchdown is made, a goal is scored (compare this to school, where students may wait days or weeks for feedback on their work). Sports are also extremely information-intense. Measurement is objective, precise, and continuous. The three modalities of quantity, quality, and level are everywhere present. Normally, these are expressed in terms of points, percentages, and levels of difficulty. In basketball, for example, players score one point for a free throw, two for a regular shot, and three for a long shot. This roughly corresponds to the level of difficulty of each shot: typically, a free throw is made with around 75 percent accuracy, a regular shot at 40-50 percent, and a long shot at 30-40 percent.

While all sports share information intensity, team sports are particularly information-intense. This is because of the necessity to track individual contributions, in addition to team results. Thus, baseball, soccer, and football all have developed sophisticated ways of measuring the offensive and defensive skills required for each position. The precision of the measurement techniques are equally impressive, with digital technology tracking fractions of inches and thousandths of seconds—even in a game played on a 100-yard field over a period of hours. Sports are also highly structured and repetitious, greatly facilitating measurement of results, prediction, and progress tracking.

Although information intensity and immediate feedback are two of the most important common characteristics of sports, positive alignment of purposes certainly adds an additional important element. Scoring a touchdown is the joint purpose of the running back, blocker, coach, and fan. Clearly the development of teamwork as a result of positive alignment is one of the principal virtues of team sports. Positive alignment, though, is also very much in evidence in highly individualistic sports such as golf or tennis, although the relevant group is more narrow, restricted in range to parent, coach, and perhaps family members or fans. Clearly, one can see the relatively greater importance that families play in developing individualistic sport skills versus the more important role the peer group plays in developing team sport skills (the intense devotion of the "tennis mom" of popular cliche seems missing from the football or soccer field). Individual measurement and effort in support of a team goal reinforces positive alignment of peer purposes. When a team goal is not present, however, individual measurement does not result in positive alignment of peer purposes.

Sports are also highly illustrative of the use of challenge to create motivation and interest. One of the primary ways sports creates challenge is through competition. Of course, lopsided competition is not challenging for either side. Therefore a great deal of effort is made to match equally-skilled competitors or teams against each other. Division One teams play other Division One teams. Similar age groups or weight levels compete, as do contenders of beginning, intermediate, and advanced skill levels. Besides various pairing techniques, handicapping is also sometimes used. Finally, one is challenged to "beat the clock" or achieve a "personal best," instances in which measurement alone seems adequate to provide the necessary motivation.

Sports illustrates the importance challenge plays in the positive alignment of purposes. Teamwork is unimportant when playing against an easy opponent. So, too, is good coaching or fan support. It is only challenge and high expectations that makes positive alignment necessary or achievable.

We typically hear the argument that our world makes too much of sports and not enough of academics. It might be more useful, however, to consider how the feedback and alignment of purposes exemplified by sports are responsible for their universal appeal—and how we might build these same elements into other human systems where we wish to increase motivation and achievement. It is with that end in mind that we turn again to the classroom.

The Accelerated Reader: a Technology-Based Cybernetic Approach to Literacy[28]

It is popularly believed that the U.S. has a reading problem in the sense of students not learning to read. Actually, virtually every student who receives sustained reading instruction learns how to read, at least at a first or second grade level. The problem is not that students are not learning to read, but that they don't learn to read well. A growing number of students fail to achieve reading automaticity, the skill of reading fluently with comprehension. At an adult level, this means being able to recognize instantly with comprehension approximately 50,000 to 100,000 words[29]. It is axiomatic that the best way to develop a robust vocabulary is to practice reading, to be exposed to a variety of quality literature over a significant period of time. Reading literature fosters all kinds of other cultural development as well; it is no accident that we refer to knowledgeable people as being "well-read." Practice makes literate. The conviction that promoting reading practice was the best way to promote literacy was the impetus behind the development of the Accelerated Reader.

The Accelerated Reader (AR) technology-based literacy program is one of the best-selling reading software programs in the United States. It is used in over 27,000 schools nationwide. Several small-scale control studies and a recentlycompleted large-scale control study involving more than 2,500 schools demonstrate AR's effectiveness in improving student reading skills[30]. I believe the success this program is demonstrating is directly a result of the cybernetic concepts that are exemplified by its design. Cybernetic concepts were also used to design the AR companion teacher training program, called Reading Renaissance®, developed by the Institute for Academic Excellence[31]. Nationwide, in the last two years, approximately 25,000 educators have been trained in Reading Renaissance techniques. Typically, teachers who fully adopt the Reading Renaissance program and use the Accelerated Reader software to manage 60 minutes of in-school reading practice report their students' standardized test scores increase at twice the normal rate[32].

From a cybernetic perspective, the Accelerated Reader is a closed-loop feedback control that dramatically increases information regarding reading practice. It is an accounting system for reading. Computers are used to measure students' quality, quantity, and level of reading and feedback this information to students, teachers, and parents. Following are some of the basic features of the Accelerated Reader program and the related cybernetic principles illustrated.

<u>Student Chooses Book to Read</u>—Student choice helps create a positive alignment between the instructional purpose of promoting trade book reading, and the student purpose of achievement. When the student selects his own book, his cognitive interest and ego-enhancement is likely to be greater. Also, student book choice is often influenced by the reading of peers or important others, and serves the drive to affiliation.

<u>Student Reads Book</u>—The experience of reading itself is the first and most important feedback information the student receives (experience is included within the sensor-measure stage of the feedback control model). The information feedback from the experience of reading is a very significant part of the total information feedback the student receives. If the book is interesting, contains useful information, or has characters the student can identify with, there will be positive alignment between student and instructional purposes.

<u>Computer Test</u>—The computer multiple choice test on the book the student reads measures whether the student has read the book. There are tests on over 8,000 books available within AR. Tests contain 5, 10, or 20 literal questions, depending on the length of the book. Literal questions are used versus inferential or critical questions, because the purpose is simply to measure reading practice. Inferential questions also tend to be biased against lower ability readers, adding a source of noise to what should be clear feedback information for these readers. The computer test is a very efficient

and objective method of measuring reading practice, especially compared to other methods such as book reports or journal entries.

One of these advantages is the immediate feedback students receive. The test also has another cybernetic function: it provides challenge. Students who know they will take a test pay careful attention to their reading. Finally, the test greatly enhances positive alignment by increasing the students' sense of achievement.

Points—Each book the student reads has a point value based on its length in words and its readability level. The following formula is used to assign points to books:

$$AR\ Points = (10 + Reading\ Level) \times \frac{(Words\ in\ Book)}{100{,}000}$$

The computer awards points to students based on the percent correct achieved on the test. Thus, point values incorporate the three domains of good measurement: quantity (words read), quality (percent correct), and level (readability level of book). Points provide a large amount of summary information on reading practice, are comparable over time and place and between students, and contain much higher information content than other measures of reading practice (such as a tally of books read).

Reports—There are up to 21 different reports available from the AR system. Virtually no record keeping is required of the teacher; the computer software maintains the entire database of student records. Three of the more important AR reports are discussed briefly below.

A TOPS Report, which stands for Three Opportunities to Praise a Student, is printed at the completion of each testing session. This provides an information link between the teacher and parent and an opportunity for them to praise. More importantly, it also can provide negative feedback when a student fails a test. If a student fails a test, it likely means there was no positive experience when he read the book. Negative information feedback means the system is not in homeostasis, nor is there positive alignment. Intervention is required by the teacher. If the teacher fails to intervene, it could lead to permanent negative alignment.

Another useful report is the At-Risk Report, which provides both criterion reference and normative information on students. Again, it is based on the idea that negative feedback is the most important kind of information. Students who have low points or low average percent correct are highlighted for teacher attention.

A third report is the Student Record Report, also known as a student portfolio report. This contains a complete listing of all the books the student has read. In the lengthy process to develop outstanding reading skills, having a complete progress report can greatly increase one's resolve and sense of satisfaction. It also provides useful information for teacher diagnosis of reading problems.

As this brief explanation demonstrates, AR is an implementation of a closed-loop feedback control which provides a rich source of well-differentiated information about reading practice. According to cybernetic theory, this should help bring the process into control, reduce student variance by normalizing student success, and increase the quantity of reading practice—effects I believe have been amply demonstrated in both research and practical application[33].

However, this description also makes it apparent that AR by itself cannot ensure homeostasis. Homeostasis requires teacher intervention. Without teacher intervention, negative feedback will not cause change and positive alignment. Also, the computer by itself cannot give recognition or praise to satisfy a student's ego-enhancement needs, or social reinforcement to fulfill the need for affiliation; only humans can do that. Finally, we must remember that our purpose is to produce growth and improvement—a dynamic condition that requires that students be consistently challenged. Here, too, is an important role for the teacher. In the case of literature-based reading, the students need to be challenged to read longer, more difficult books with more complicated, and eventually more interesting stories. It is only through taking on challenging books that reading growth can accelerate. Challenge is necessary to satisfy both learning and motivational purposes.

The Reading Renaissance program was developed in recognition of the central role teachers play in challenging, instructing, monitoring, intervening, and assuring positive alignment. Some of the principal features of Reading Renaissance are as follows:

Status of the Class—Teachers visit one-on-one with each student daily to check the Student Reading Logs, which record their day-to-day reading progress in the interval between AR tests. The daily Status of the Class increases the frequency of the feedback, improves the loop response rate, and, thereby, reduces the risk of failure. One-on-one time also permits interpersonal feedback and improves positive alignment of student and teacher purposes.

Zone of Proximal Development (ZPD)—This is an application of Vygotsky's concept of assisted development[34]. The idea is to maximize growth by having students concentrate reading practice at a challenging-yet-successful level in which context supports learning. AR provides information feedback from test results that help students and teachers select books in each individual zone. This constant feedback and adjustment makes for an extremely dynamic readjustment of set-points; old set-points are "forgotten" as the system seeks homeostasis at higher and higher achievement levels.

Certification Levels—Six certification levels keep students challenged to continually master text at higher levels of readability. The teacher monitors this and recognizes students for their achievement. Certification levels add a significant amount of goal information and challenge, and provide clear direction.

Peer Positive Alignment Techniques—Various techniques are used to specifically enhance peer alignment. These include frequent group book discussions, cooperative reading team competitions where heterogenous mixed teams compete, and peer paired reading in which older or more able students are paired with less able students. When the pair complete a book, both tutee and tutor take an AR test to measure results and provide feedback. Peer paired reading is a one-on-one tutoring technique, the powerful effectiveness of which has been well documented[35]. Cybernetically, peer paired reading has many advantages over other one-on-one tutoring such as the more expensive Reading Recovery program. Peer paired reading has demonstrated great effectiveness for both tutee *and* tutor, and positive peer alignment is achieved (as opposed to the negative peer alignment that can occur with pullout programs).

Parent Positive Alignment Techniques—Besides the many AR reports sent to parents, parents are encouraged to participate in various ways such as home read-aloud activities and Family Reading Night, which is a weekly open house in which parent and child come to school to read and take AR tests.

Principal's Challenge—The principal challenges the entire student body to achieve a semester or school year goal; a schoolwide celebration marks the achievement of the goal. This simple technique does much to align purposes of faculty, students, parents, and peers.

Model Classroom Certification—This teacher recognition program, sponsored by the Institute for Academic Excellence, is the primary method for measuring the occurrence and quality of the Reading Renaissance implementation. It provides challenge and clear objectives to the teacher and an opportunity for significant achievement recognition. It is also the primary measurement technique the Institute uses to measure its performance. Achievement of Model Classroom certification provides a great deal of summary information about the teacher and the classroom. It assures positive teacher alignment to student and instructional purposes. Unlike many certificate programs in which teachers are certified if they complete training, Model Classroom teachers are certified upon accomplishment of results.

It is difficult to overstate the transformation that happens when the informational power of Accelerated Reader technology is harnessed by a teacher using the cybernetic techniques of Reading Renaissance. The contrast to the entropic classrooms Goodlad describes is dramatic. Perhaps the best way to show this difference is through the words of two Reading Renaissance Model Classroom educators:

> "Accelerated Reader is the first program I've ever come about which absolutely lets the child know that they are truly reading. And lets the teacher know they're truly reading, from the teacher standpoint. . . Just as the child can be successful with the program, I as the teacher am being successful in the teaching of reading because I have feedback. I have a tremendous amount of reading behavior at my fingertips to look at on the Accelerated Reader. I'm suddenly confronted with something I never had, and that is the absolute certainty of what I'm doing and that it's being effective. Or, if it isn't effective, I know how to adjust what I'm doing to make it effective; so from those two standpoints, it's been pure enjoyment for me for the last five years."

—Jonathan Lind
Grade 4-5
Sudley Elementary School
Manassas, VA

> "Imagine a world where students are so excited about reading that they want to spend every available minute reading books. This dream has become a reality in my classroom. A Student Summary and an At-Risk Report is printed daily to help monitor student success and give an indication that intervention is necessary. Student Records are printed each week for students to take home. Comments concerning students' progress are included on report cards and progress reports. It is so exciting to be a part of a program that not only gets children to read, but helps them learn to love reading. It is truly the greatest thing to happen to education in my lifetime!"

—Tracee Kitchens
Grade 4
Bleckley Elementary School
Cochran, GA

Conclusion

Our public school system is founded on the ideal of the common school in which each student has an equal chance to a good education. The system's purpose, then, is not simply to create academic opportunity, but to foster democracy and freedom by reducing the extreme variance of learning that would otherwise occur. The common school ideal is exactly analogous to the cybernetic concept of a well functioning system operating under closed-loop control. A "good" cybernetic system reduces variance (educational inequality); a bad system, an open-loop system, either has no effect or actually increases variance. Measured on the basis of whether there is an increase or decrease in educational variance, our national school system does not perform well. When we compare students ranked among the top 25 percent in scholastic performance to those in the bottom 25 percent, we find that for each year of school, the difference in academic achievement increases. On a nationwide basis, by the time students reach the eighth grade, achievement tests reveal the top 25 percent of eighth graders average a grade-equivalent score of 12.9 years, while the bottom quartile average a grade equivalent score of 4.9—a difference of eight grade levels[36]. A cybernetic approach suggests we determine a system's purposes by examining the system's output. Examining the output of our schools, we would have to conclude the purpose of our schools is to create an academic elite, the opposite of our common school ideal.

When Horace Mann first promulgated the concept of the common school, schools were relatively small neighborhood places where children of all ages learned together. This close physical environment, with its mix of younger and older students, naturally supports high feedback information, positive alignment of purposes, and shared challenge for all students. Such a system reduces rather than increases variance. Today, schools are large institutions in which students receive less contact with teachers, are largely cut off from the communities they live in, and interact with peers who are segregated for homogeneity of age and ability. When we understand how such conditions restrict our ability to align the human purposes of students, educators, and community, it is not surprising that school outcomes are so different from our intentions.

Norbert Wiener wrote *Cybernetics* at the end of WWII, at the beginning of the computer age, an age he helped create. In the postwar years, faith in progress and science were at a peak. The scientists and intellectuals of that era had little doubt that solutions to the world's problems were within their grasp. Yet, after fifty years, as wondrous as the technological breakthroughs have been, our problems are not much different. And while much has changed in the way schools look, in terms of the day-to-day process of learning in the classroom, change has been nearly nonexistent.

I have attempted to demonstrate that a cybernetic understanding of human systems in general, and specifically of educational systems, can provide important insights that hold out the possibility of improvement. However, they are insights which we can only avail ourselves of if we accept, as Mann did, that our society has a vital interest in providing the greatest possible education for all of its citizens, and that this purpose mandates us to exercise control over the educational system. This control must be exercised by all the participants in that system, but most critically by educators, and by students themselves; for only when the system is managed in a way in which the fundamental human needs of each are fulfilled will we maximize the vital outputs we seek—learning and freedom for all.

Notes

1. Wiener, N. (1948). *Cybernetics*. John Wiley, New York.

2. Although cybernetics has not had much impact in social sciences and education, it is not from lack of trying. There has been more work done on cybernetics in Europe and especially Russia than in the United States. A survey of the history and application of cybernetics can be found in the following book: Richardson, G. (1991). *Feedback thought in social science and systems theory*. Philadelphia: University of Pennsylvania Press.

3. This section is based on two principal sources: Wiener, op.cit. & Beer, S. (1959). *Cybernetics and management*. New York: John Wiley and Sons. Beer was not in Wiener's original group, but became one of cybernetics' principle proponents and extended cybernetics into the area of operations research.

4. There are many different configurations possible for a feedback control. In some cases, the feedback signal is shown connecting to the comparator versus the set-point. In such a conception, the set-point is externally fixed; feedback has no impact on the set-point. The Figure 1 configuration was chosen specifically because a fixed set-point is not likely to be a reality in most social systems. A fixed set-point may be a reality in a mechanistic system, but in human systems, the set-point is very likely to be influenced by the sensor feedback stage. Also, sometimes a feedback control diagram does not include an output stage, the idea being that the control is separate and apart from the output. While there is nothing wrong with that conceptualization, the author has found it typically leads to less confusion to include an output stage.

5. Wiener makes the distinction between Newtonian concepts of time in which time is reversible, and Bergsonian concepts of time, or the time of statistical mechanics and probability in which time moves forward only. Wiener, op.cit.

6. McClelland, J., McNaughton, B., & O'Reilly, R. *Why there are complementary learning systems in the hippocampus and neo-cortex*. CMU Tech Report PDP.CNS.94.1 March 1994.

7. Information theory seems to have been invented simultaneously by Wiener and Shannon, a Bell Labs scientist, although Shannon typically is cited as the originator. Shannon, C. "A mathematical theory of communication," *Bell System Journal*, vol. 27, p. 379-423, July 1948, and p. 623-656, October 1948. The important concept that Shannon discovered is a way of quantifying the information content of a message. Information theory has become a more active scientific area than cybernetics, and it is debated whether cybernetics is a subset of information theory or the other way around. See also Singh, J. (1966). *Great ideas in information theory, language, and cybernetics*. New York: Dover Publications.

8. Goodlad, J. (1984). *A place called school: Prospects for the future.* New York: McGraw-Hill.

9. The concept of positive alignment of purposes is distinguishable from the concept of common purpose precisely because in an instructional setting, there are several distinctive systems which have non-overlapping and unequal purposes which must be considered separately. The concept of common purpose can lead to a lack of attention to the needs and idiosyncrasies of the different interrelated systems, and therefore, lower effectiveness.

10. McKenna, M., Kear, D., & Ellsworth, R. (1995). Children's attitudes toward reading: A national survey. *Reading Research Quarterly*, 30, 934-956.

11. Isaac, S. & Michael, W. (1995). *Handbook in research and evaluation.* San Diego: EdITS/Educational and Industrial Testing Services.

12. The law of parsimony is also known as the law of economy or Occam's razor after William of Ockham (1285-1347), a philosopher and scholastic.

13. Clay, M. (1993). *Reading recovery: A guidebook for teachers in training.* Birkenhead, Auckland, New Zealand: Heinemann Education.

14. There is a very active debate as to just how successful Reading Recovery is. See Center, Y., Wheldall, K., Freeman, L., Omthred, L., & McNaught, M. An evaluation of reading recovery. *Reading Research Quarterly,* 30, 240-263, and Pinnell, G., Lyons, C., DeFord, D., Bryk, A., & Seltzer, M. Comparing instructional models for the literacy education of high-risk first graders. *Reading Research Quarterly*, 29, 9-38.

15. Fuchs, L. (1995). *Comparing performance assessment to instruction: Comparison of behavioral assessment, mastery learning, curriculum-based measurement, and performance assessment.* Reston, VA: ERIC Clearinghouse on Disabilities and Gifted Education, the Council for Exceptional Children; Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, Educational Resources Information Center.

Kane, M. & Mitchell, R. (Eds.). (1996). *Implementing performance assessment: Promises, problems, and challenges.* Mahwah, NJ: L. Erlbaum Associates.

Marzano, R. & Jesse, D. (1987). *A study of general cognitive operations in two achievement test batteries and their relationship to item difficulty.* Aurora, CO: Mid-continent Regional Educational Laboratory.

16. Elley, W. (1989). Vocabulary acquisition from listening to stories. *Reading Research Quarterly*, 24, 14-187.

17. Turlow, M. et. al. (1989). *Social validity evaluations of three interventions targeting increases in academic engaged time.* University of Minnesota, Instructional Alternatives Project. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, Educational Resources Information Center.

18. Bloom, B. (1980). The search for methods of group instruction as effective as one-to-one tutoring. *Educational Leadership*, 41, 4-17.

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20. The importance of speech as a window to cognitive processes has been a major interest of one of the leading cyberneticians, Gordan Pask. There are also linkages between Pask's work and Vygotsky and Piaget.

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Terrance Paul, J.D., M.B.A., the founder and chairman of the Institute for Academic Excellence, has conducted extensive research into learning motivation, educational assessment, and reading practice. His works include *Patterns of Reading Practice* (1996), the largest study ever done on the impact of literature-based reading; *The Impact of the Accelerated Reader on Overall Academic Achievement* (1996); *The National Reading Study* (1992); *The National Study of Literature-Based Reading* (1993); *How to Create World Champion Readers* (1993); and *How to Use the Accelerated Reader in Grades K-4* (1994). Paul is also executive editor of the manual, *Fundamentals of Reading Renaissance* (1994).

Since its beginning in 1993, the Institute has trained more than 25,000 educators in the principles and techniques of Reading Renaissance, a literacy acceleration program based extensively on Paul's theories and research.

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