The Public School System: A Dynamic Model of Community Standards, Students, Teachers, and Resources

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Abstract

Problem

Public school systems have severe problems that are rooted in the fundamental dynamics of the system. A list of problems includes:

- Declining performance
- Diminished standards
- Relativistic performance assessment
- Student motivation
- Confused objectives and curicula
- Teaching fads
- Cultural heterogeneity
- Non-educational responsibilities of schools
- Social pathology
- Administrative confusion
- Disenchantment with public schools

Purpose/Objective

The objective of the effort was to reduce the public education system to its basic elements: standards, students, teachers and resources; and then to analyze the dynamics of such a system as it responded to three fundamental kinds of disruption: resource waste, teacher diversion, and student distraction.

Method/Approach

A system dynamics model of a public education system was constructed using STELLA II. It was exercised according to a 5 X 4 factorial experimental design that examined the behavior of 12 dependent variables under the 20 conditions specified by the factorial design.

Findings

Results were summarized as a series of parametric plots. For example, plotting Performance X Cost per Performance point gained across all conditions of degradation revealed a significant interaction effect. That is, performance costs at high standards are much less per unit of performance gained, (and much less sensitive to disruption) than those at low standards. Eight major findings are discussed, and a discussion of each of the major identified problems is offered.

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Introduction

A recent article by Albert Shanker (April, 1992), President of the American Federation of Teachers, places much the blame for poor student performance on the backs of parents and on the relatively low standards of work and performance they impose upon their children and schools. In contrast to oriental parents, American parents come across largely as lazy, brain-dead, know-nothings who prefer popularity and sports to academic performance (my words, not Mr. Shanker's). His thoughts were stimulated by two studies (Stevenson and Stigler, 1992, and Caplan, Choy and Whitmore, 1992) that compared education in Asia and of Asian refugees in the U.S. (where, and among whom, standards for work and academic performance are high and clear) and among Americans in the U.S. (where standards for work and academic performance are weak and confused). Such differences in standards, and in the differential student effort they engender, account for much of the superiority of Asian students, both in Asia and in the U.S., Mr. Shanker suggests. From this point of view, the school system has three factors: public standards and expectations, student motivation and effort, and teacher effort and effectiveness. In the same week, an article in The Atlantic by George Leonard (May, 1992) describes "The End of School" as we know it: books and teachers are to be replaced largely by interactive, computer-accessible data bases and computer-mediated instructional programs operated by teams of students who teach themselves under the management of teachers. Stephan Jobs, the founder of the Apple Computer Company, in a recent (April 1992) public television special that anticipated the information super highway, described a not-so-distant dream of making the knowledge contained in the library of congress available to the home via fiber optics and computers.

The Central Problem: A search for First Principles

Following is a list of education system problems inspired and derived largely from the excellent essays of Albert Shanker, head of the American Federation of Teachers.

> Declining Performance. Performance on standardized tests is deteriorating relative to past performance and to the performance of the students of other nations.
>
> Diminished Standard. Standards of academic performance, and the expectations for excellence and hard work from both students and society at large are declining. Public education is declining because of the requirement to redress too many social problems, and by the distractions of the escape and entertainment ethic that has come to dominate social values in the affluent television and information age.
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> Performance Assessment. Diminished and confused standards, confused objectives, confused curricula, and untested teaching methods lead to an inability to tell good performance from bad, either for students or for teachers.
>
> Student Motivation. The system kills it. Kids who start out with zest and energy soon turn into indifferent, easily saturated, passive sponges. Escape and entertainment seem to attract much more student attention than the fun and excitement of learning.
>
> Confused Objective and Curricula. Educational objectives and the means to attain them are confused with broad, poorly defined social objectives that have little to do directly with learning.
>
> Methods and Resources. Teaching methods are changing. Fads are in vogue (holistic reading instruction, for Heaven's sake!). Controversy rages over the obvious (phonics, for example. See Adams, 1992). Technological opportunities

abound. No one knows what is best, and it all costs too much. The methodological revolution and technological revolutions have created confusion and a desire for strong pedagogical leadership.

Population and cultural heterogeneousness. The melting pot is not melding the diverse populations into a single (Western Civilization) core culture (Schlesinger, Jr. 1992). Confusion concerning educational objective and curricula result.

Increasing non-educational responsibilities for the schools. As the schools are asked to substitute as full-time parents, as police, and as social workers because of dysfunctional families and neighborhoods, educational functions are diluted. As schools are asked to correct all sorts of social ills from racism to delinquency and teenage parenthood, educational functions are side tracked.

Social pathology. Crime and violence, the culture of poverty, and the culture of escape and distraction come to dominate the schools and distract students and teachers from the tasks and joys of learning.

Disenchantment with public education. As standards drop, as performance drops, as the schools are required to do everything but teach, as sloth and distraction come to dominate the value system, the middle class is fleeing to the suburb and to private schools to the extent that it can to try to save itself. It no longer wants to fund educational and social failure with its taxes.

Administrative confusion. The ideas of bussing, vouchers, contract performance, tuition, privatization, magnet schools, student courts, and on and on indicate that the system is lost and confused about its role and its objectives in society.

Which of the above problems should be choose to address with a system dynamics model? How do we go about selecting the first order problem(s). What are the basic elements of a system that might indicate a way solve them? How are they organized? What are the motive forces that make them operate? What are the resources that mediate and sustain them? What are the processes that take place? What are the limits that regulate and constrain them?

Standards, students, teachers and resources, the vital quartet. This paper describes a dynamic model of these four elements of education in an attempt to illustrate a method for determining the optimum allocation of public funds to the development of standards, to the motivation and support of students, to the motivation and augmentation of teachers, and to the development of teaching resources.

Standards

The total system seeks to meet the standards of the society within which it is imbedded. True, the standards move or track performance at the same time they drive it. But they drive it with a cultural lag, a smoothed delay. If standards are not high and clear, (almost) all the money resources in the world will not make the system perform well. Indeed, if any element of the feedback structure illustrated in Figure 1 is deficient, performance is deficient. The lessons of the dynamic model developed in this paper are simple, loud, and clear on this matter.

Students

The student model is based upon well-understood factors in the learning process. While the documentation of basic learning processes is beyond the scope of this paper, it is important to note that we have modeled learning rate as a function of three kinds of factors: 1) basic endogenous learning drives such as curiosity and manipulation; 2) positive exogenous factors such as learning assignments, and goals, and negative exogenous factors such as distractions and

diversions; and 3) learning-how-to-learn skills, learning accelerators acquired as a consequence of both endogenous (internal drives, goals and skills) and exogenous (external goals, assignments, and practice) factors. In combination, these factors create a learning system (student) that demonstrates inherently robust positive, positive-tending feedback loop behavior, but which, under certain conditions, can be made to collapse into positive, negative-tending feedback loop behaviors. The student model embodies formal ways to characterize such aphorisms as: "the more you know, the more you want to know", "the more you learn the better you learn", "practice makes perfect", "the closer you are to the finish line, the harder you try", and so on. All of these common-sense aphorisms have their counterparts in formal learning psychology research. The student model used in this work reduces them to the three learning rate factor types mentioned above. The task of the educational system, then, is to provide goals, motivation and resources, and to minimized distractions and disruptions (noise) from the educational system within which the student subsystem functions.

Teachers and Resources

Teachers and resources are modeled as facilitators of student learning. The level of teacher effort and the level of resources applied track cultural norms that are tied ultimately to student performance and to the absolute standards of the community. The fractional contribution of each to the student's performance is adjustable.

The Quartet: A Four Element Model of the Education System

The four elements of the educational system integrate the student model we discussed above into a system comprising students, community standards, teachers, and resources. The four elements are arranged into three interacting negative feedback loops of the same generic architecture. Figure 1 illustrates the configuration. The system seeks to meet the standards set by the community by adding student effort, teacher effort, and community resources to the task as required. The cost of teacher labor and community resources are computed to estimate the total cost of the system operation. The cost to achieve performance improvements, the costs of disruptions to students and teachers, and the cost of the diversion of community resources to purposes other than learning are also computed.

Student learning, teacher work, and community resources are treated as levels. Each level has input and output rate equations that accommodate inter-loop communication requirements (see below). The levels are considered to be normalized to the society at large. That is, the initial levels of student performance, of teacher effort, and of community resources reflect their percentile position in a sample of communities in the total society. Performance is measured with respect to the society at large in percentile points. Accordingly, an improvement from 50 to 60 points in student learning means that the student body has risen from the 50th percentile to the 60th percentile in the society on standardized performance measures of some kind. Likewise, if throughout the course of the simulation, teacher effort has escalated from 50 to 60, it means that the teacher-hour to student-hour ratio has increased 10 percentile points relative to the society at large. The same normalizing scheme holds for community resources.

Each of the loops is regulated by three "constants" that move according to the performance of the students. We will discuss this matter in some detail below. But for now, it is important to know that the model accommodates rising (and falling) expectations by adjusting the references for all three system loops according to a very long time constant. That is, if student performance continues to improve (or decline), the standards for teacher effort also will increase (or decrease), and the standards for the amount of community resources will increase (or decrease). Accordingly, the whole system can bootstrap itself to the limit of its wealth or decline to the limit of its pathology and sloth.

Each of the loops has the capacity to accommodate scenarios of various kinds. Resources can be wasted by corruption, and they can be augmented by a larger society (State and Federal resources, for example). Teacher effort can be drained by administrative and non-instructional work such as

counseling, policing, and parenting. Student effort can be augmented by assignments of any size and frequency, and they can be depleted by any distraction scenario of interest.

The influence of any loop on any other loop can be adjusted by various "gain" settings in the model. That is, the importance of the teacher effort to student learning can be adjusted, the importance of educational resources to teacher effort and to student learning can be adjusted, and the effect of student performance upon the effort of teachers and upon the propensity of the community to provide resources also can be adjusted. These can be used to calibrate the model to the real world. Indeed, the writer adjusted them at considerable length to get the specimen model illustrated here to behave in a way that seems reasonable.

The time horizon for a given simulation is adjustable. We have selected 12 years for our work. It seems reasonable to track the ups and downs of a given class through the system for the standard 12 grades. It also seems reasonable in terms of the adjustment time constants of communities. iMiracles in education do not happen over night. In order to check that the model reaches a steady state under various conditions, we have extended the runs on occasion to 48 years.

Loop Details

Each of the three negative feedback loops is illustrated in Figure 1. They all have the same simple negative loop form, but with some important peculiarities. Each loop reference point is influenced by cultural expectations (the expect. factor). Student expectations are derived from community standards and from student performance relative to long-term cultural expectations. Cultural expectations are derived from measures of student performance that have been smoothed over a very long time (our favorite, the one used throughout the discussion in this paper, is a smoothing period of 24 years). Student expectations influence all major loops in the system: the students themselves, the work plans of the teachers, and the resource funding plans of the community. If student performance continually falls short of community standards and their own cultural expectations, the teacher work plans, and the community resource plans reflect that drop, and the performance of the entire system declines in spite of the high community standards.

There are three fixed standards (standards that can be changed only between simulation runs) that tend to regulate the system if it is in reasonable balance, and if it is not disrupted too severely. These are the community standards for student performance, the professional work standards for teachers, and the community resource standards allowed to support both teachers and students. These are identified in the "clouds" that inject themselves into the three loops illustrated in Figure 1.

There are three kinds of disruption factors that may impinge upon the system according to any magnitude profile over time. Student effort may be disrupted by any amount over any time period, teacher effort may be diverted in any amount over any time period, and community resources may be diverted or wasted in any amount over any time period. Additionally, resources may be augmented in any amount over any time period.

Student effort is "multiplied" by factors that reflect extraordinary teacher effort and community resource levels, and by student assignment scenarios. By extraordinary effort, we mean only that effort that is over and above the effort required to maintain current student performance levels within whatever disruption environment that is simulated. Such extraordinary effort contributes to improved student performance, by definition. Improvement effort can be defined and captured, and its costs can be assessed. as described below. Accordingly, we are able to identify the costs (both in learning and in dollars) of the effects of various disruption scenarios on the improvement (or lack of improvement) in student performance.

All three loops are limited by the society within which they function. Their performance cannot exceed the 100th percentile on any parameter.

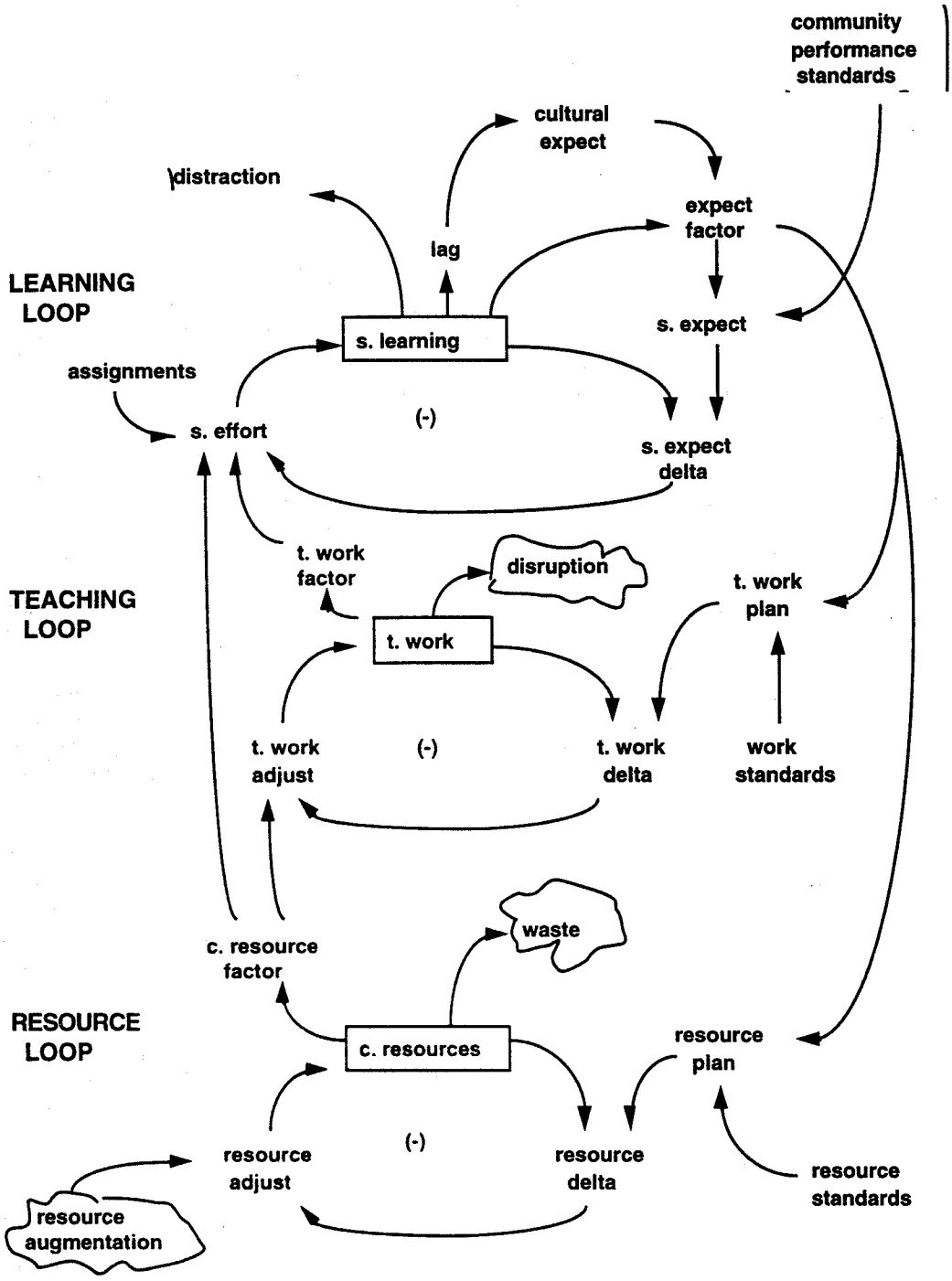

FIGURE 1 THREE BASIC LOOPS OF THE EDUCATIONAL MODEL

Cautionary note

The loop gain adjustments, while very handy, permit the theorist to "wire in" his a priori prejudices, and to make the model behave in ways to reinforce them. Beware! This opens up the issue of model validity and the processes by which it is established. The subject (alas) is beyond the scope of this Paper.

The Cost Model

The cost model computes the cost per percentile unit of student performance, and the cost per percentile unit of student performance change (improvement or degradation). The computation of the cost per percentile unit of performance is straightforward. It computes the cumulative teaching effort cost, and the cumulative resource expenditures, sums them , and divides the total by the percentile performance at the end of the experimental period. The computation of the cost per percentile unit of improvement is a bit more convoluted. It involves the following logic. If the culturally determined student performance expectation factor is greater than 1, and if the teacher effort is greater than expected (according to prevailing work standards), and if the expenditure of resources is greater than expected (according to prevailing resource expenditure standards), then the cost of such expenditures are accumulated as teaching costs associated with performance improvement, and resource costs associated with performance improvement. The computation of the cost per percentile unit of performance improvement is then possible.

Model Performance

All model variables can be observed and plotted over time. In order to assess the performance of the model, we devised the 5 X 4 factorial experiment. The experimental design employed five scenarios involving community resources, work disruption, and learning disruption across four levels of community standards. Community standards were varied over four percentile levels (50, 60, 70, and 80). The initial level of student performance for all scenarios was set at the 50th percentile. The five scenarios involved the following conditions: 1) a baseline scenario that responded to community standards without adding or subtracting anything, 2) a scenario that involved community standards plus added resources, 3) a scenario that involved community standards combined with reduced resources, 4) a scenario that involved community standards, fewer resources and less teacher effort, and 5) a scenario that involved community standards, fewer resources, less teacher effort and less student learning. In general the scenarios involved doubling the normal resource waste and teacher diversion rate for a period of five years, and disrupting the student learning capacity (his learning rate) by 50 percent for a period of five years.

For each of the above 20 experimental conditions, we captured twelve dependent variables: s. learning, t. work, c. resources, work improvement cost, resources improvement cost, total improvement cost, improvement cost fraction, work cost, resource cost, total cost, cultural standard, and student expectation.

The principle findings of the twenty experiments are summarized in Figures 2 through Figure 6. Figure 2 illustrates the rise in performance, standards, and motivations when resources are adequate, when expectations are high, and when disruptions and distractions are held to a minimum: a sustained twelve year march toward community educational goals. Figure 3, on the other hand, illustrates what happens in a community when a seven year regimen of resource waste, teacher diversion, and student distraction is imposed on the system. Performance, standards, resources and motivations collapse toward oblivion until order is restored at year seven of the scenario. At that time, a dramatic recovery begins. Over the remaining five years of the simulation run, the recovery returns the performance to where it was at the beginning (at the 50th percentile), and takes it beyond to the 56th percentile. This recovery illustrates the compounding effect of mutually reinforcing corrective feedback that occurs in systems when appropriate conditions are created. Does this model behavior represent the behavior of educational systems in the real world? We think that it does, and that the present model may be adjusted to represent any school system that creates and announces clear student performance standards, that uses standardized methods to assess and reward student and teacher performance relative to those standards, and that is willing to establish substantial teacher bonuses of some kind that are based on their student's performance. Without clear standards, and the methods for assessing performance relative to such standards, feedback in the form of knowledge of results, and in the form of rewards and punishments cannot be applied to students and teachers. The system drifts, victimized by the imperatives of the second law of thermodynamics. It may be saved, possibly, only by the self-sustaining positive loops that may operate: student curiosity, and

learning skill, and by the long-remembered standards of idealistic teachers who may impose their own internalized standards on selected students.

Aside comment

One suspects that it is, and always has been, over the millennia, the idealistic teachers who have made education work in the face of community indifference, incompetence and sloth. One also suspects that we ask too much of them: to be fuel, oxygen, and throttle setting for the learning engine.

Figure 4 describes student performance as a function of community standards and the five scenarios described above. The results illustrate dramatically the two main effects operating within the system: 1) the effect of an increase in community standards from 50 to 80 percentile points; and, 2) the effect of the five degradation scenarios as it depressed performance across all standards levels. The dominant effect in this series of runs was the community standards. However, in the series of scenarios illustrated in Figure 4, the degradation lasted for only for five of the twelve years of the simulation. When the degradation was increased to *ten* of the twelve years of the simulation, the effects were devastating: the system collapsed as performance fell a total of 59 points across the four community standards levels.

Figure 5 illustrates the effects on the cost per unit performance (the efficiency) of the five waste, diversion and disruption scenarios across the four community performance standards. The cost per performance metric is defined as: total cost/final performance score. What is operating here is, that as higher standards create higher performance, the cost per unit performance drops, and the *efficiency* of the system increases across all five degradation scenarios. Figure 5 also illustrates the strong interaction effect

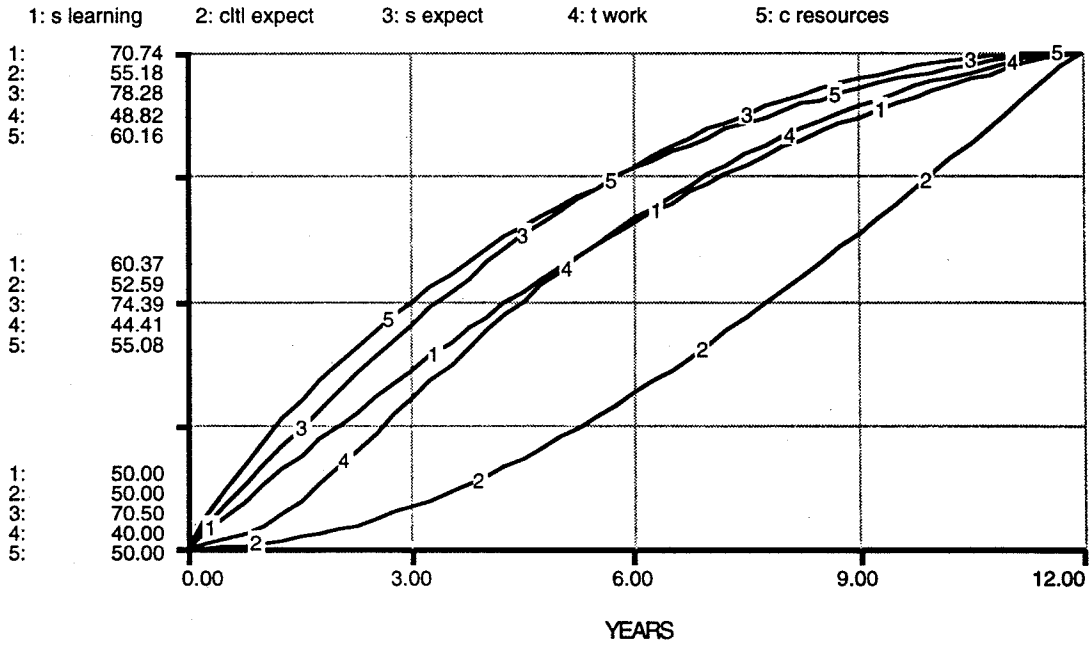

FIGURE 2 NORMAL GROWTH IN THE SYSTEM WHEN STANDARDS ARE HIGH AND DIVERSIONS AND DISTRACTIONS ARE MINIMIZED

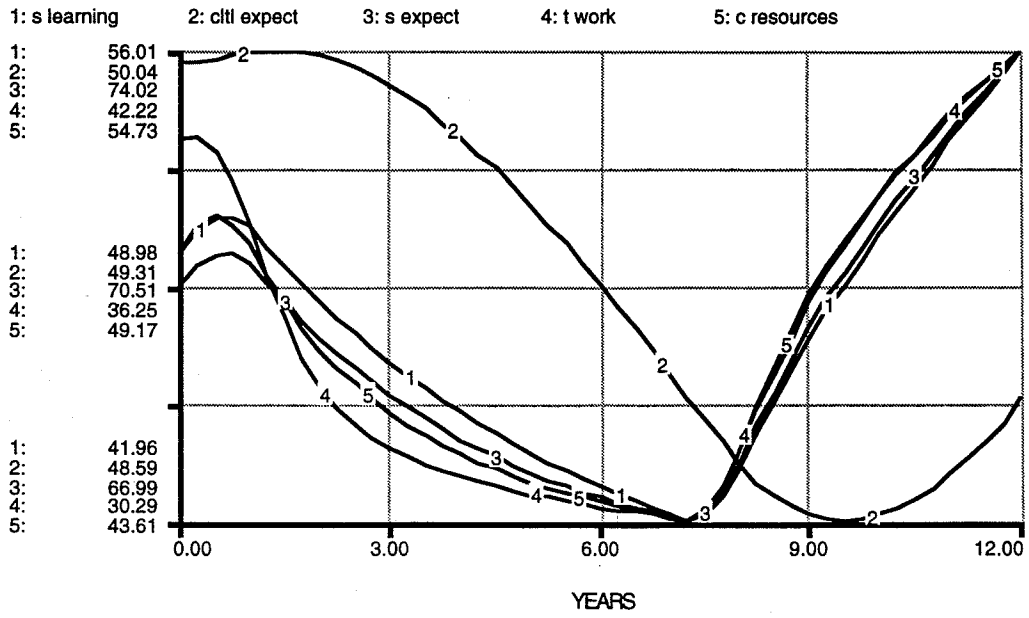

FIGURE 3 SEVEN YEARS OF DEGRADATION AND SUBSEQUENT RECOVERY WHEN STANDARDS REMAIN HIGH AND DIVERSIONS AND DISTRACTIONS ARE SEVERE

between increasing standards and increasing disruption: namely, that low standards are affected much more by disruption scenarios than are high standards. The general convergence of the scenario curves from a spread of 270 efficiency (cost per unit performance) points at the low end of the performance standard range to a much narrower spread of 100 efficiency points at the high end of the standards range illustrates this interaction. This (substantial) interaction reflects the fact that as (internalized student) standards increase, the student learning expectation feedback delta (motivation) increases *relative to other (disrupting) factors in the model,* thus reducing the effect of the degradation scenarios across increasing standards. It demonstrates classic positive loop exponential "take-off" behavior. It represents a "damn the torpedoes, full speed ahead" attitude that grows stronger the closer one gets to an increasingly valued target.

Figure 6 illustrates with high drama the effects of waste in an out-of-focus education system. In the baseline case, where there is not diversion or disruption operating, fully 64 to 68 percent of the money in the system is devoted to pursuing the rising standards and expectations of the community and students (at ever increasing efficiency). In the worst case scenario, where resources are wasted on non-instructional tasks, where teachers efforts are diverted by demands other than teaching and motivating (good subject matter teaching is the best student motivator of all), and where students are diverted from study by disciplinary disruptions, only 14 to 28 percent of the (increasing) money is devoted to student performance improvement. Fully 72 to 86 percent is spent simply to keep even (at the 50th percentile).

Cultural standards and student expectations are illustrated in Figure 2 and Figure 3. In each case, cultural expectations lag the long term performance of the students, and reflect a slow adjustment to reality. Also in each case, the (internalized) student expectations are tied both to the slowly responding cultural expectations *and* to the absolute standards of the community (in these cases, the community target was the 70th percentile). Because they are continually significantly higher than performance, student expectations appear to reflect a perhaps hyper-optimism with respect to reality. True, they are leavened by experience, and they go up and down with performance, but they are continually significantly higher (in number) than performance. This latter fact may be interpreted to mean that the model is not realistic, that it may not be realistic to assume that the students in this system internalize to the extent illustrated the standards set by the community.

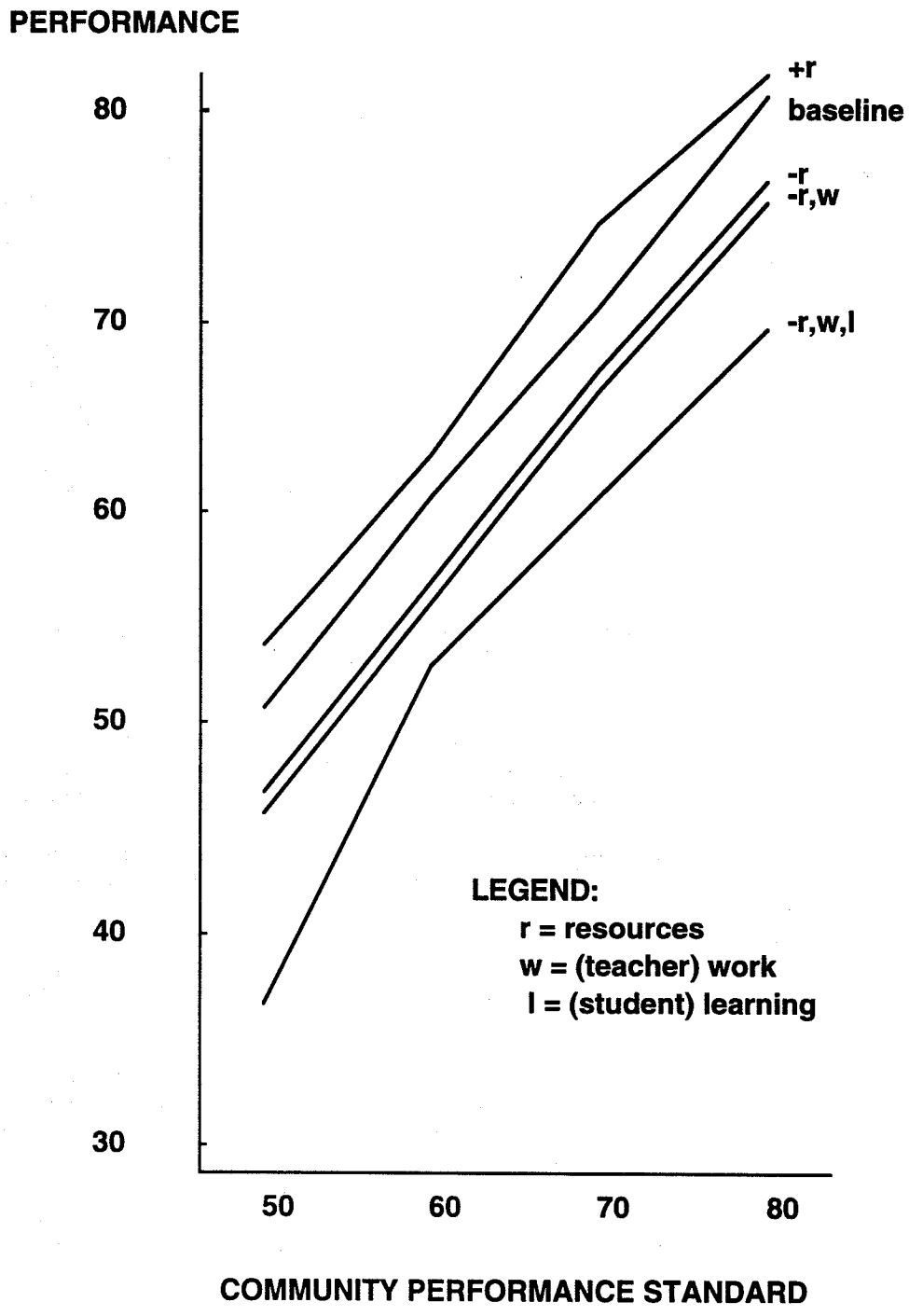

FIGURE 4 STUDENT PERFORMANCE AS A FUNCTION OF COMMUNITY STANDARDS, RESOURCE WASTE, AND WORK AND LEARNING DISRUPTION

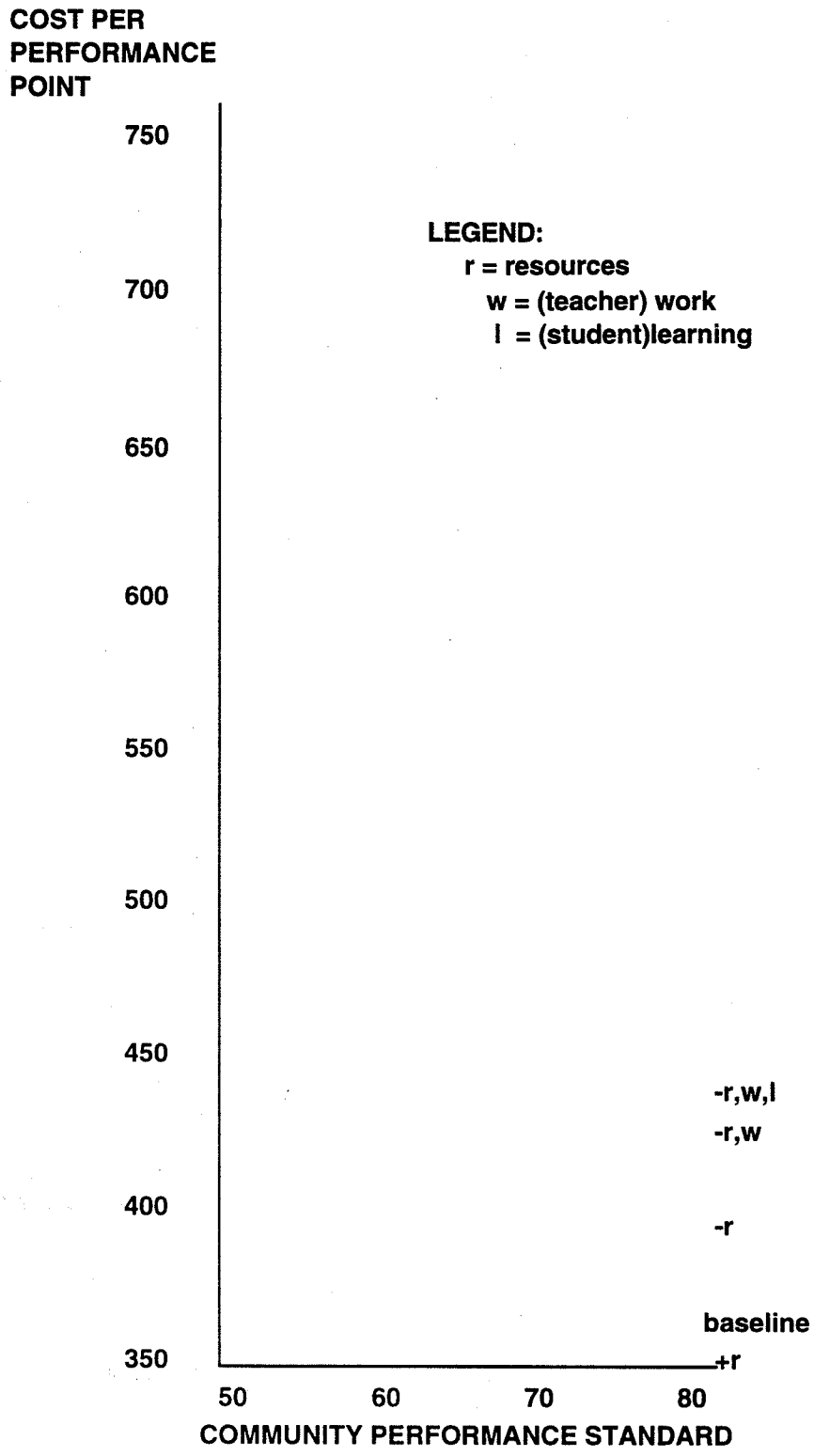

FIGURE 5 THE COST OF WASTE, DISRUPTION AND DISTRACTION WITH INCREASING STANDARDS

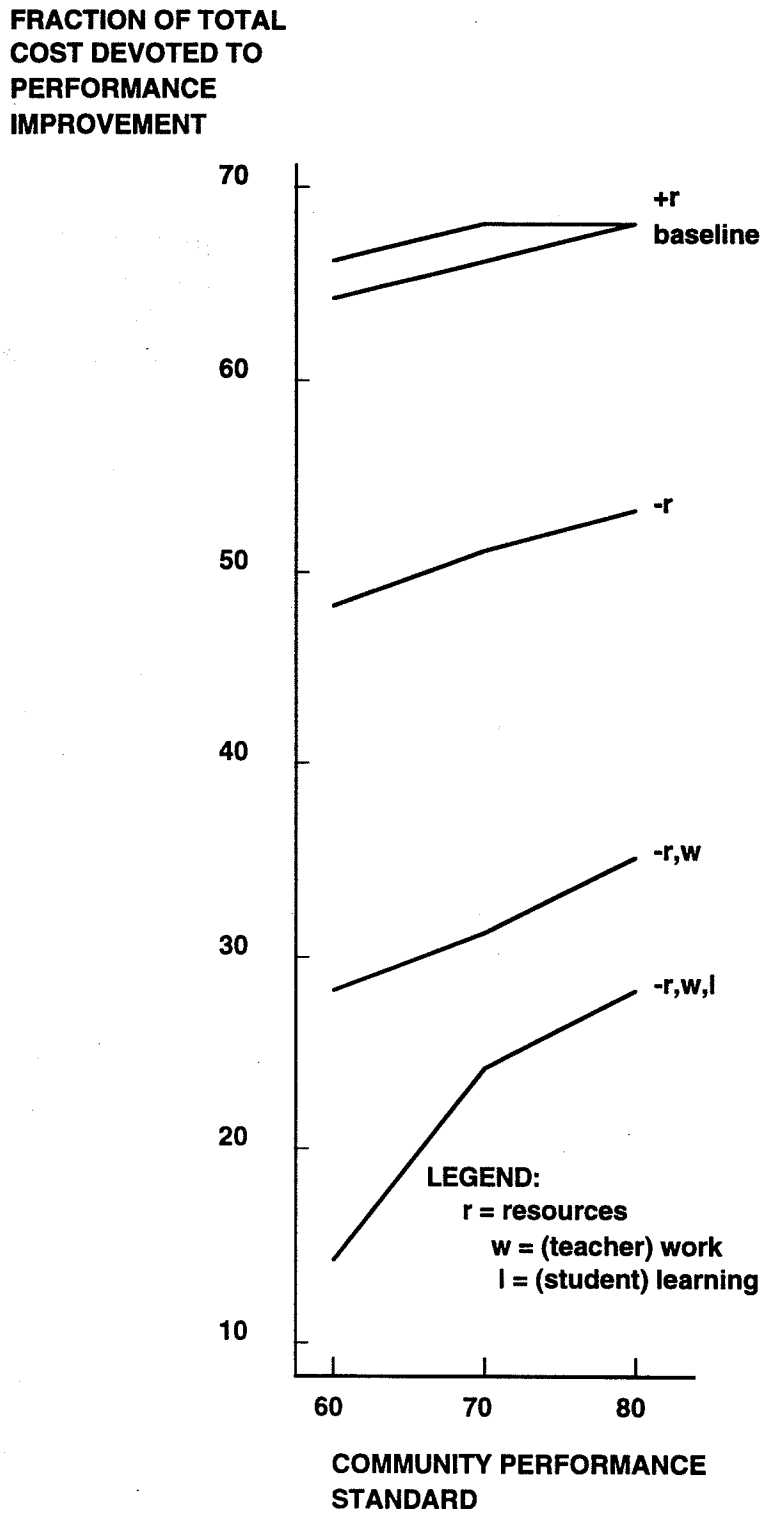

FIGURE 6 THE SEVERE DEGRADATION OF EDUCATIONAL EFFICIENCY ACROSS DIVERSION AND DISRUPTION SCENARIOS

But what is in the number? What does S. expect. = 66 mean? S. expect. is a number that depends upon every other number in the feedback loop of which it is a member. But what does it *mean,* we ask. That is a very difficult epistemological question we have not space to answer here. Suffice it to say, that it is an inferred, or derived construct that represents a moving goal, target, reference point, objective, call it what you will, for the student loop. It is assumed to represent the internalized momentary goal the student sets for himself as he goes about learning. S. expect delta represents the *difference, error, gap, correction,* call it what you will, between the student's actual performance and his internalized performance expectation (based upon the fixed external community standard, and upon the slowly varying cultural expectations generated by past student performance). If the delta, error, gap, or correction is large, the student learning rate is proportionately large. If the delta, error, gap, correction is large, the student's curiosity is high, his goal gradient is high, his motivation is high. S. expect is a number that makes the gap get smaller over time in a way that reflects the performance of actual students in an actual school system. It is a theoretical construct that (we think) is necessary to account for the facts of learning. Its "true" value is the one that is assumed when the model (theory) reflects a satisfactorily wide range of system behaviors, and the one that is required when all of the objectively measured variables in the system have been measured across an acceptably varied set of conditions. It is the internal motive force, the magnitude of the explosion in the combustion chamber of the student's learning engine that has the community's standards as its throttle setting, the oxygen of curiosity in its intake, and community's learning and teaching resources in its gas tank.

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