Predicting Education System Outcomes: A Scientific Approach[1]

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Feb. 7, 2006

Overview

Many well-intentioned people want to improve education. So do we. We believe that education could be far more effective, efficient and satisfying than it is in our current educational systems—both K-12 and higher education.

Educators who have taught for a while have seen several widely talked about changes come and go. For example, some of the innovations have been referred to as: site-based management, constructivist classrooms, technology integration, school restructuring, and yes, even systemic change. Educators have correctly observed that not much has really changed from what they can see. They view new calls for change with a certain detachment and skepticism. We find these attitudes understandable, given the history of numerous innovations that have largely failed to make significant improvements in education. Many think: "Just another buzzword. Just another fad. Ho-hum."

[1] We want to acknowledge two people who helped with preparation of this chapter. Joyce Koh, a doctoral student in Instructional Systems Technology at Indiana University, was instrumental in creating Figures 1-8. They are even more interesting when animated in PowerPoint, as she created them originally for making conference and class presentations. Kathleen Brophy Frick, a lifetime teacher of young children up through adults, served as an editor who helped us write in a language that is less technical. She made us see gaps that needed to be filled for explaining our ideas more clearly.

Why? We believe that the following questions have not been adequately addressed:

- "Change what?"
- "Change how?" and
- "How do you know the change is working?"

We must know *what* to change in order to know *how*. We must know whether the change accomplishes the goal and that the change does not have negative, unintended effects. Change for the sake of change is nonproductive. And, without knowing what to change, the "how" is irrelevant.

As an analogy, consider an old bridge that is failing—it is structurally weak and is impeding the flow of traffic. If the bridge is not fixed, it will collapse and vehicles will plunge into the river. When engineers design a new bridge, they utilize adequate scientific theories. No one in modern times would consider designing a new bridge by trial and error.

Up until the present, we have had no *valid* way of predicting that new educational system designs will work any better than what we now have. We have had no valid way of describing the elements of any educational system or of evaluating the effects of change throughout the system. New designs and curricula have been patches—much like fixing rust spots on an old car with body filler and paint, putting on new seat covers, or getting new tires. The overall structure remains unchanged.

Many researchers have focused on the change *process*. We believe it is equally important to focus on the outcomes of change—i.e., how well the new system is predicted to work and how well it does work. We need both approaches—process and outcomes: they are complementary. The change process could be effective, *but* the resulting new system may not have the desired outcomes. The new system may be effective, *but* the change process may leave staff and families, teachers and students bitter and exhausted. For best results, both processes and outcomes must be satisfactory. This has not been predictable.

We are working squarely on the problem of predicting education system outcomes. The predictions must be based on scientific theory, its implications, and data to support the theory. If the predictions are not based on scientific theory, then how can we justify expending great effort and resources, only to end up with something that is no better—or possibly even worse—than what we now have? It is no wonder that educational practitioners often distrust, resist and undermine the efforts of educational reformers. The stakes are very high. The consequences of mistakes can be devastating—particularly when changing a whole system of education.

Understanding systemic change is not a simple matter. Educators will need to learn new thinking patterns. Hart (1993) has noted that the vast majority of individual belief patterns do not contain dynamic cycles. Cognitive maps of belief structures tend to be linear with few, if any, feedback loops. Hart indicated that exceptions occurred with those people in professions which taught them to think in dynamic cycles (e.g., ecologists, systems engineers). Similarly, Senge (1990) has provided insight into business organizations by identification of archetypal patterns of *dynamic* cycles. These patterns are not easily described or understood through static print and diagrams. To address this problem of understanding, Senge and his colleagues have developed role-playing activities and computer simulations in order to help business people understand these patterns of dynamic relationships—some of which run counter to individual intuitions about how systems such as business organizations grow and change.

For these reasons, we believe that it will be very helpful to educators, if they can use computer software that will help them to design new educational systems. The software must be usable, flexible, portable, and user-friendly. If the computer programs are not user friendly, then the change process will not be adopted by busy education professionals. The products we are developing must be rigorous and usable, generalizable and adaptable.

SimEd Technologies

SimEd Technologies consist of four parts:

1. The 'Get Ready, SET, Go!' change model,
2. The theory model options set called Axiomatic Theories of Intentional Systems (*ATIS*),
3. Computer software: Analysis of Patterns in Time and Configuration (*APT&C*), and
4. Computer software: Predicting Education System Outcomes (*PESO*).

Designed to work together, *SimEd Technologies* use computer technology to help describe educational systems, predict system changes and document the outcomes of change.

We will describe the '*Get Ready, SET, Go!*' model to predict educational system outcomes to guide the change process. This inquiry-based change model will utilize adequate theory and computer programs which are currently under development. Then we will give more detailed discussion of other parts of the *SimEd Technologies*. The model is outlined below.

Get Ready, SET, Go!

Phase 1: Get Ready

- Identify the specific current education system to be improved.
- Over some interval of time, measure system properties using our computer software *ATP&C* (more below).
- Predict outcomes under existing conditions *if nothing is changed in the system* using our computer modeling tool *PESO* (more below).
- If these outcomes are what are wanted, then do not modify the system. However, if the outcomes are not desired, then the system must be changed so that the desired outcomes can be obtained. If change is desired, proceed to Phase 2.

- **Phase 2: SET**
  - Use *PESO* software to model newly envisioned educational system designs, the desired feasible changes.
  - Run *PESO* predictions out far enough in time to make sure all the consequences of the newly designed system would be acceptable. This iterative process will determine the outcomes of the system under the conditions defined by the changes. Are these the wanted outcomes? If yes, proceed to Phase 3.

- **Phase 3: Go!**
  - Implement the new design chosen in Phase 2 in the education system.
  - After the new education system has been established, then over some interval of time, measure system properties with *APT&C* software.
  - Verify that the measures confirm the predicted system outcomes. If not, then analyze both the Phase-2 and Phase-3 processes to determine what modifications are required.

***PESO* Simulation**

We are building a software simulation called *PESO*: *Predicting Education System Outcomes.* *PESO* will model system concepts and allow educators to focus on the predictions. *PESO* is a logic-based simulation.

The most familiar simulations are scenario-based programs that provide "scripts" to determine outcomes. A familiar example is SimCity (see http://simcity.ea.com/). Scripts for simulations can be narrative or quantitative. Narrative scripts characterize the qualitative parameters of a system—i.e., the social, philosophical, and individual descriptions and the uncertainty of future outcomes. Quantitative scripts define the scientific facts, known or credible data, and quantitative models that are used to determine future outcomes. However, in both narrative and quantitative scripts, the content is closed. There are a limited number of possible outcomes, and the scripts predetermine the outcomes.

If the script lacks fidelity, then users may learn the wrong things. For example, consider what might happen *if* modern flight simulators that are used to train military and commercial pilots lacked fidelity. A pilot in the simulator might discover when encountering something called 'wind shear' while trying to land the plane on the runway, that if she or he pulls hard on the yoke, this would keep the plane from crashing in the simulator. However, in reality such an action will not work and the real plane would crash. These would be devastating consequences for making the wrong decision. The better course of action is to not attempt to land the plane under such conditions, and wait until the storm passes. Thus, a simulation script that lacks fidelity could be misleading and dangerous.

Friedman (1999) recognizes these kinds of problems with scenario-based models in his report, "The Semiotics of SimCity," when he states:

> Of course, however much "freedom" computer game designers grant players, any simulation will be rooted in a set of baseline assumptions. SimCity has been criticized from both the left and right for its economic model. It assumes that low taxes will encourage growth while high taxes will hasten recessions. It

> discourages nuclear power, while rewarding investment in mass transit. And most fundamentally, it rests on the empiricist, technophilic fantasy that the complex dynamics of city development can be abstracted, quantified, simulated, and micromanaged. (n.p.)

On the other hand, *logic-based* models depend on the logic of a theory that has been shown to be valid for the targeted empirical system, in this case, an education system. The theory describes the empirical system in terms of its affect relations, properties, and axioms. The theory is then used to project outcomes founded on the theory with respect to input parameters. The instantiated axioms would generate a set of outcomes, which become input parameters that instantiate yet more axioms. Unlike scenario-based models that are closed due to the limited number of scripts, logic-based models potentially have an infinite number of outcomes. Such models are more flexible.

PESO is a logic-based software tool that makes predictions for a specific educational system, based on current conditions. One must first observe properties of that system and determine how the values of those system properties change over some time period. Properties may increase, decrease, remain constant, or increase to some value then decrease. When those changes in system property values are entered into *PESO*, the software finds relevant axioms and theorems which match those conditions, and then executes the logic of Axiomatic Theories of Intentional Systems (*ATIS*: Thompson, 2005). *PESO* effectively applies relevant parts of the theory in order to make predictions of what will happen in the system.

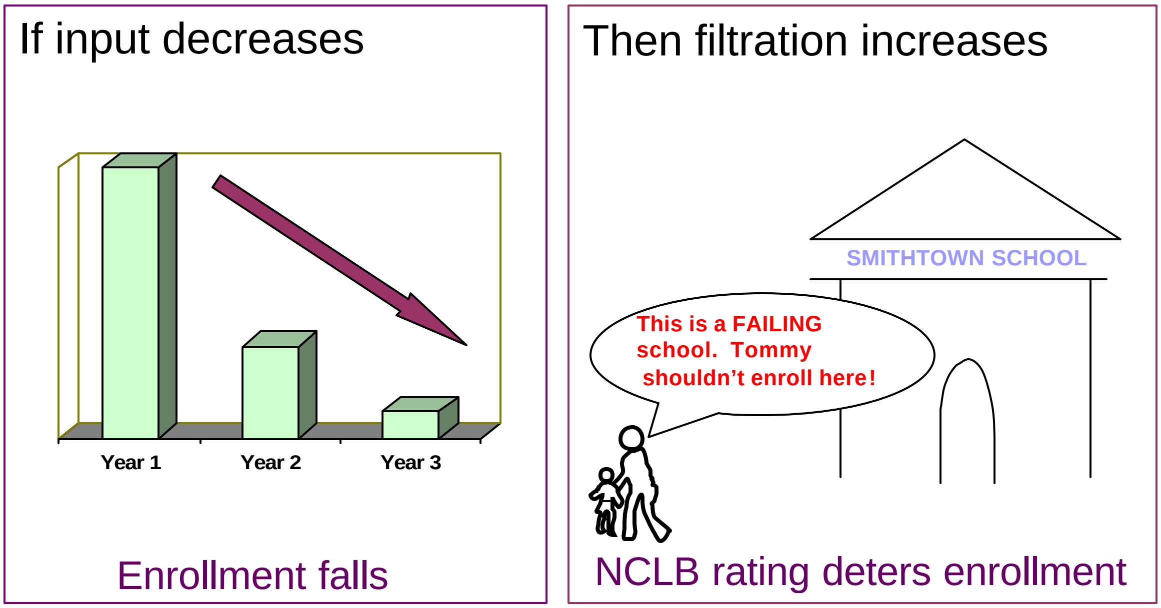
Significant progress has been made on *PESO* software. The current prototype is built in Flash using a programming language called ActionScript. Each of the axioms, antecedents, consequents, properties, and property attributes are treated as ‘objects’. What this technical capacity of software means is that the software can be easily extended and modified as the theory is further developed and validated. In effect, *PESO* handles the complexity of the theory by carrying out the reasoning according to the theory and the specific conditions that are typed into the software. The examples and figures below illustrate how *PESO* does the reasoning – based on the axioms and theorems of *ATIS*.

An Example of PESO: Predicting Education System Outcomes

In the United States, all public schools are affected by *No Child Left Behind* (2001) legislation. NCLB requires schools annually to assess student achievement at numerous grade levels. Based on average test scores, schools are identified as succeeding or failing. Schools that repeatedly fail to meet current state standards for student achievement are held accountable. Parents have the opportunity to send their children to different schools, if their present school is not succeeding.

Consider school #9 in Smithtown, USA, a fictitious school created for our example. Smithtown #9 has been identified as a failing school. If a particular school is identified as failing according to state standards, NCLB permits parents to move their children to a different school. What would happen as a consequence of falling enrollment? Student enrollments are a type of *input* in a school system. Axiom 13 predicts that decreasing input implies increasing filtration. *Filtration* is a system property. A filter is something that allows certain things into a system but not others. One may not think of a label of "failure" according to state standards as a filter, but it is.

Figure 1. *ATIS* Axiom 13: If system input decreases, then filtration increases.



In this example, we are using systems language that is not familiar to most educators. In each graphic, the system property (such as 'filtration') and its value (e.g., increases) is listed for an educational system. Each axiom is an "if …, then …" statement that is part of the theory. These "if …, then …" statements are called logical implications. Axiom 13 states that: If system input decreases, then filtration increases. This is not a temporal relationship, but a logical relationship. If it is true that input decreases, then it is also true that filtration increases. It does not matter which occurs first.

Does the systems theory make any other predictions? Yes, *PESO* identifies axioms 11, 10 and 16 as relevant. See Figures 2-4.

Figure 2. Axiom 11: If system input decreases, then storeput decreases.

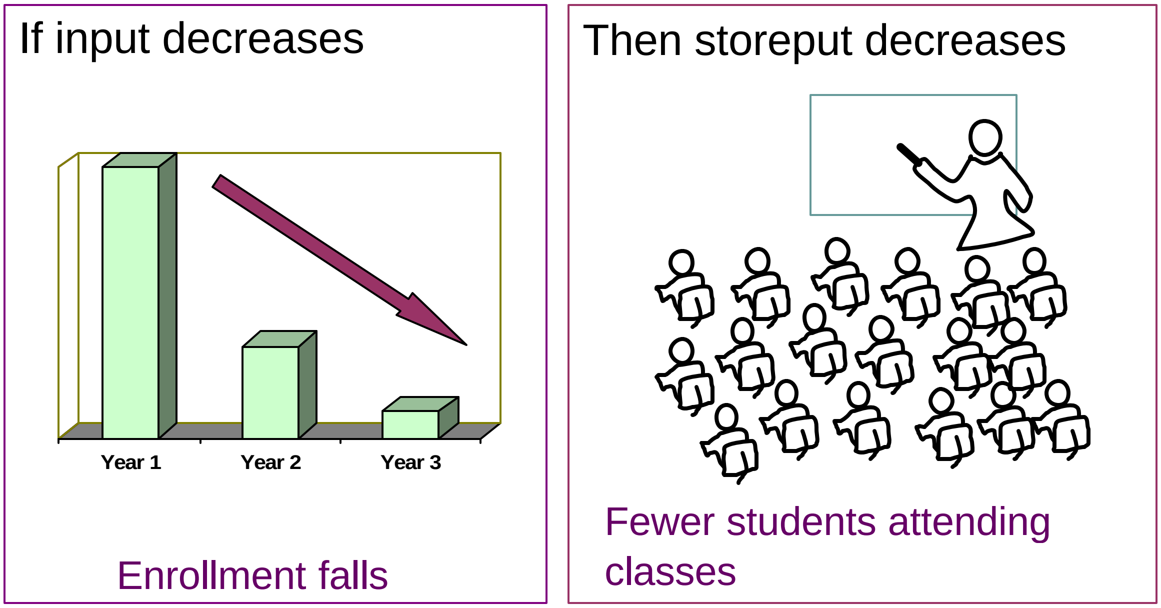


Figure 3. Axiom 10: If system input decreases, then fromput decreases.

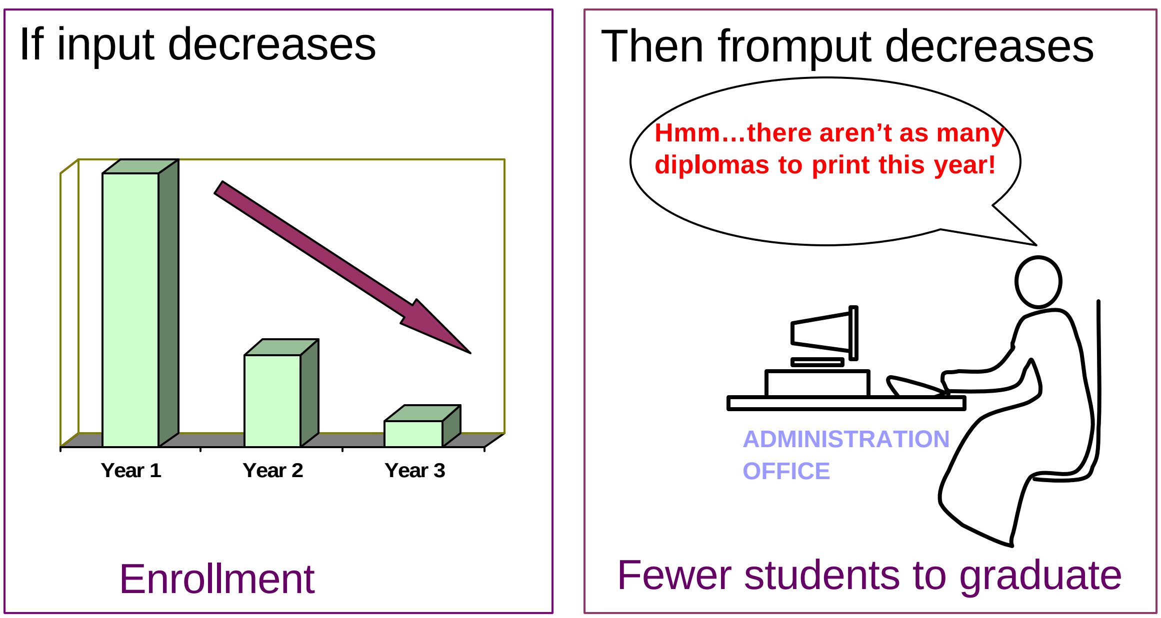
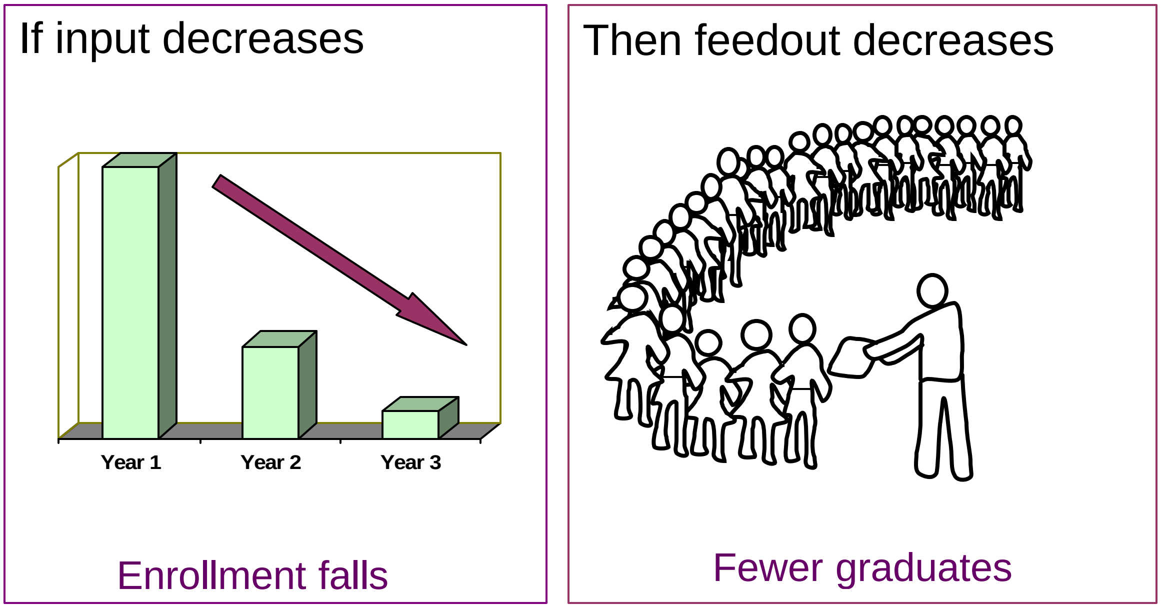


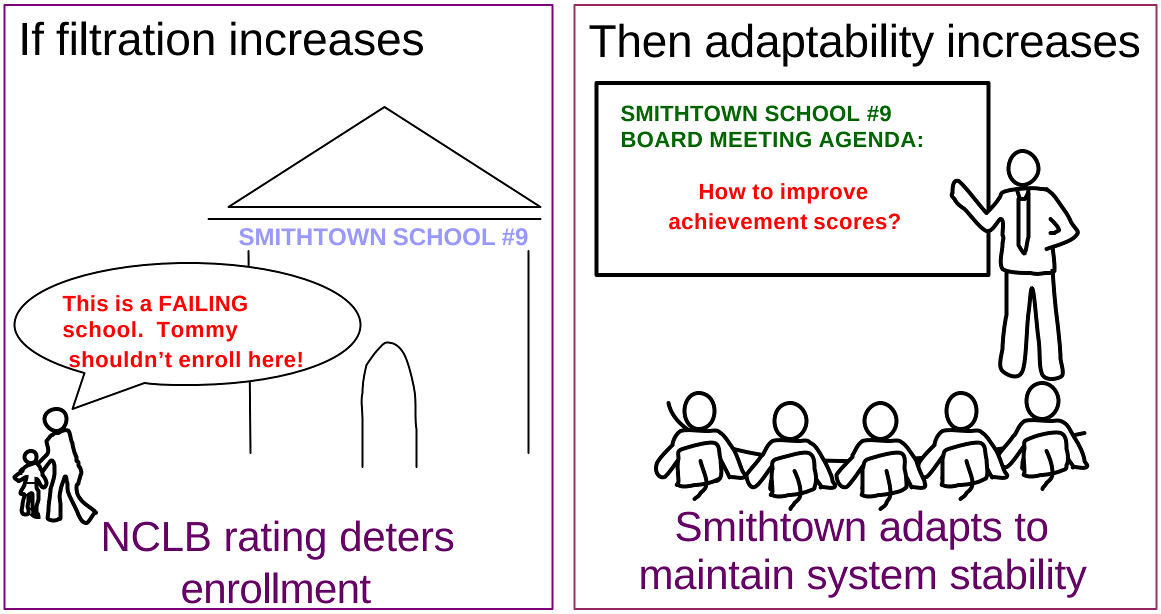
Figure 4. Axiom 16: If system input decreases, then feedout decreases.



The predictions, pictured in Figures 2-4, tell this story.   If enrollments are decreasing, then the overall number of students in the school will go down, and eventually fewer will be eligible to graduate and leave this school.

But wait—there's more! In fact, this is one of the most significant features of the *PESO* simulation: chains of implications. These chains are based on the premise: If A implies B, and if B implies C, then A implies C. To continue the example, Axiom 28 is triggered by Axiom 13. See Figure 5.

Figure 5. Axiom 28: If system filtration increases, then adaptability increases.



How could Smithtown School #9 adapt? Given the prediction that the NCLB label of 'failing school' will result in a lower student enrollment, actions can be taken to prevent that from occurring. System theory embedded in the *PESO* software offers Smithtown School options for actions that could prevent lower enrollment. Smithtown could consider actions *increasing system strongness with respect to instructional affect relations*. If strongness of instructional affect relations is increasing, what does *ATIS* predict?

055: If *strongness increases*, then hierarchical order decreases.
056: If *strongness increases*, then flexibility increases.
106: If *strongness increases*, then toput increases.
107: If *strongness increases*, then input increases.
108: If *strongness increases*, then filtration decreases.

How could Smithtown increase strongness of instructional affect relations? The school could offer more guidance of student learning by bringing in teaching aides, either paid or volunteer, or by providing more instructional technology that can actually guide learning. Peer tutoring programs in which more advanced students could tutor less advanced students would increase the guidance of learning. As can be seen above, the theory predicts that quite a few things would change in the system if strongness were increased. See Figures 6-8.

Figure 6. Axiom 56: If system strongness increases, then hierarchical order decreases.

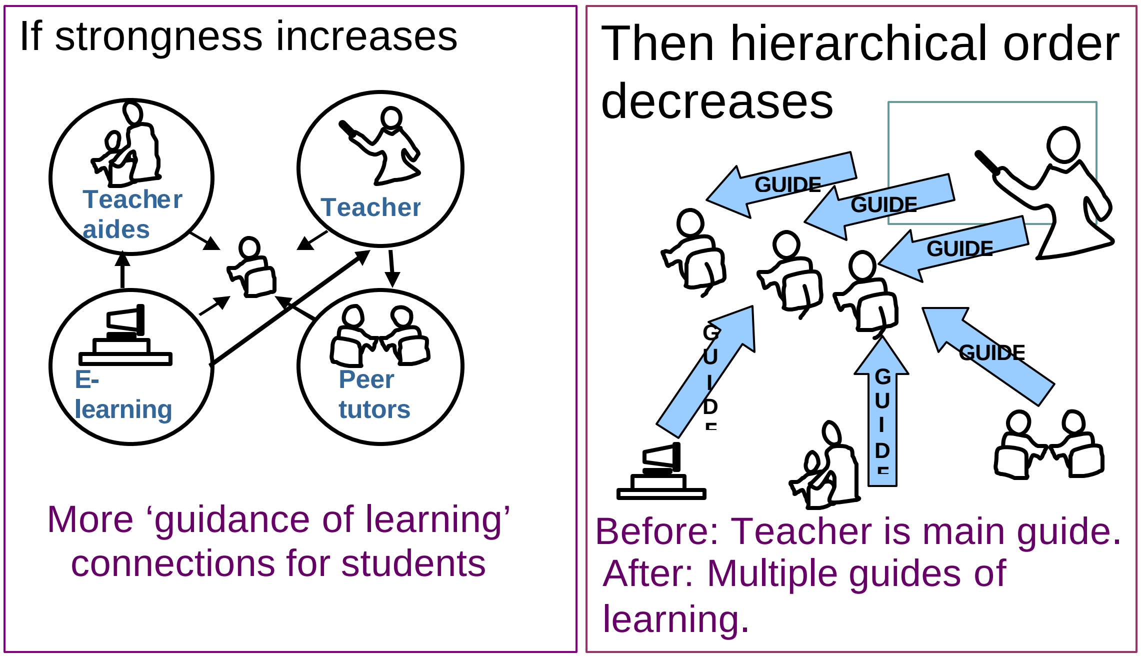


Figure 7. Axiom 55: If system strongness increases, then flexibility increases.

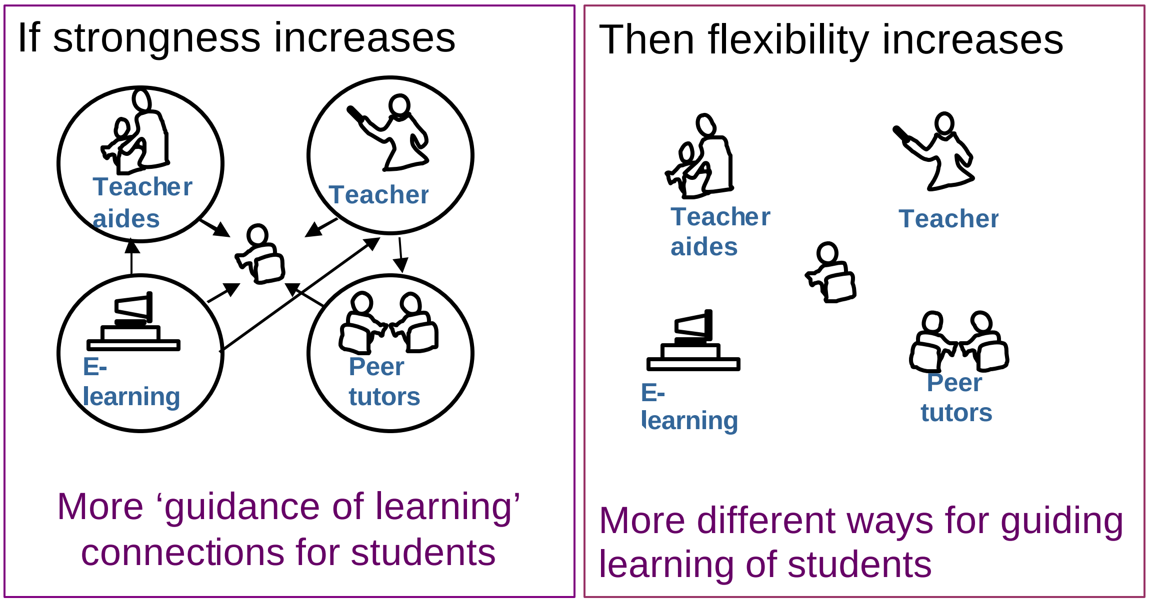
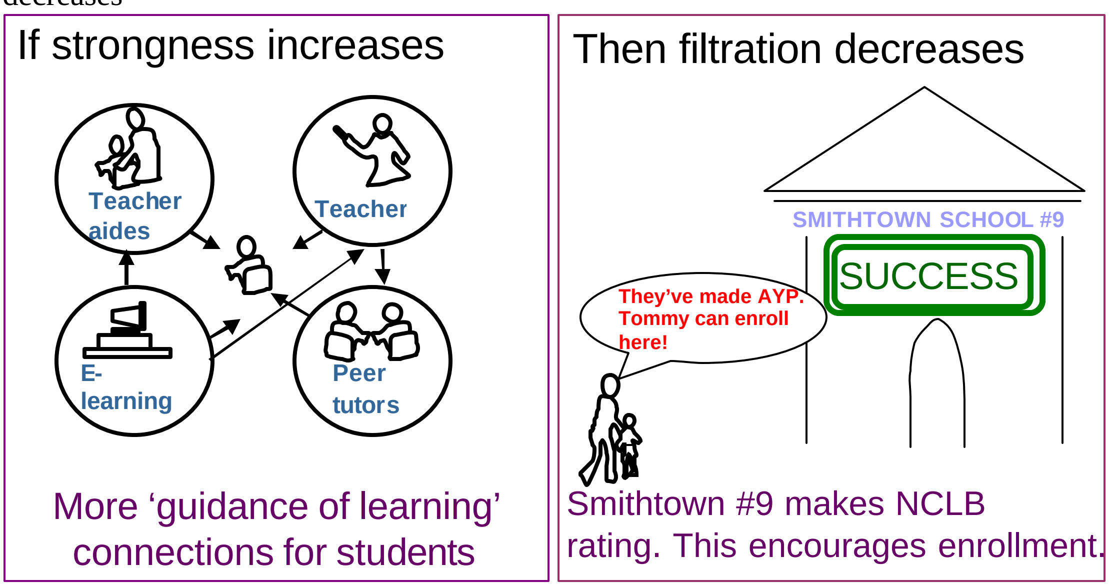


Figure 8. Axiom 108: If system strongness increases, then filtration decreases



AYP = Annual Yearly Progress (part of NCLB law)

In Figure 7, it can be seen that if strongness increases, then flexibility increases. Flexibility means here that there are more different kinds of alternative paths through which guidance can occur. For example, the teacher could be guided himself or herself by e-learning materials and then guide students, and likewise for teacher aids. Or the teacher can instruct some students, who then in turn instruct others, etc. In Figure 8, filtration is decreased by removal of the "failure" rating by meeting NCLB criteria for annual yearly progress. Axiom 108 predicts that if strongness increases, then filtration decreases.

There are additional axioms and theorems that are triggered by increasing strongness of affect relations, but space precludes discussion here.

ATIS: The Basic Concepts

ATIS (Axiomatic Theories of Intentional Systems) is a theory model options-set that is designed to construct scientific theory for certain types of behavioral systems. In particular, it is used to develop behavioral predictive theories and technologies.

ATIS is founded on a basic principle that we all rely on day-to-day to make decisions about what we do. The principle is based on Jerome Bruner's (1990) conclusion about how we derive meaning from our cultural contexts—i.e., the systems in which we live:

> We will be able to interpret meanings in a principled manner only in the degree to which we are able to specify the structure and coherence of the larger contexts in which specific meanings are created and transmitted. (pp. 64-65)

We normally do this interpretation and integration of observed phenomena intuitively. If in fact our world were not well-organized and intuitively predictable, we would not be able to function in our daily lives. We know that if we show up for work and do what we are supposed to do, that our job will still be there the next day—assuming that the larger context in which we work does not change.

Students know that if they study their text assignments, listen in class and comprehend what the instructor is saying, and work the problems for the class in such a manner that they get the correct answers, that they will receive a grade that reflects the quality of their work. That is, if a student consistently receives an “A” on quizzes, tests, reports, etc., then that student expects to receive an “A” for the course. If such students end up with a “C” for the course, they know that there is “something wrong.” Why is there something wrong? The continual integration of data into their thinking gave rise to a new structure that reaffirmed their perceptions that they were doing well. When they received a “C”, it was not consistent with the principles upon which they had been relying. Their immediate reaction—the instructor really messed up! They will go and get the grade changed because it does not reflect the structure of the system that they had come to expect.

ATIS relies on the observable fact that our lives are more predictable than not. If the outcomes are not what we expected, then we did not have full knowledge. The behavioral sciences are distinct from the physical sciences mainly in terms of what we actually know about any particular event. If we knew more about an event, our prediction may have been correct. We all believe that events are predictable—if we only knew more. It is the basic tenant of *ATIS* that such is correct.

If we did not know that, if we treat our children in a certain way, they will respond predictably, then child rearing and education would be impossible. The slogan that "all children are different" is a platitude, but, if they were, education itself would not be possible. Children are all "different" in that we know that we must treat them and recognize them individually if we want them to achieve, but we also know that children learn by just such attention.

Are different outcomes predictable for educational systems? Of course they are. Differing outcomes can be attributable to a variety of conditions including "attention of the child," "teaching skills of the teacher," "intellect of the child," "intellect of the teacher," and "physical surroundings". The question is not whether an event is predictable, but whether we know what we need to know in order to make the prediction. *ATIS* helps to focus attention on what one needs to know, and provides the structure to make a reasoned decision concerning the outcomes.

Background of ATIS: General Systems Theory

The concept of general systems theory (GST) was first introduced by Ludwig von Bertalanffy in 1949. Bertalanffy (1968) argued that there exists a general theory that could characterize the behavior of systems, regardless of whether these are scientific, natural or social; and he proposed GST as an interdisciplinary theory that could contribute to the unity of science. System behavior results from the relationships between its components, and is not just a simple summation of its parts. The characteristics of each system component therefore cannot adequately explain how the system itself behaves.

Since then, there have been extensive contributions by others in the development of GST as a logical and mathematical theory to provide an "exact language permitting rigorous deductions and confirmation (or refusal) of theory" (Bertalanffy, 1972, p.30).

Others have also contributed well-developed descriptive theories (e.g., Wymore, 1967; Cornacchio, 1972; Mesarovic & Takahara, 1975; Lin, 1987; Lin, 1999; Bar-Yam, 2003). In education, GST has been used by researchers to discuss educational systems design and systemic change, but these approaches have not been grounded in scientific theory about educational systems (Banathy, 1991; Caine & Caine, 1997; Duffy, Rogerson & Blick, 2000; Senge, Cambron-McCabe, Lucas, Smith, Dutton & Kleiner, 2000). Rather these approaches largely describe processes through which organizations can change, not whether those changes are likely to result in desired outcomes.

The *SIGGS* theory model provided the first extensive formalization of a GST model for educational theorizing (Maccia & Maccia, 1966; Steiner, 1988). Through the synthesis of four theories: Set, Information, di-Graph, and General Systems, *SIGGS* provided a logical description of general system properties, which enabled retroduction of 201 hypotheses in a theory of school systems. Frick, Hood, Kirsch, Reigeluth, Walcott and Farris (1994) extended Maccia and Maccia's work by classifying the system properties into basic, structural, and dynamic properties. This classification recognized that some *SIGGS* properties were structural as they described the connectedness between system components (*SIGGS* Website, 1996a). Yet, others were dynamic and described how patterns of relationships between system components are altered due to changes within the system or between the system and its environment (*SIGGS* Website, 1996b). Thompson (2005) recognized that the structural properties essentially defined the system topology.

To provide a theory that is logically and mathematically sound, a system-descriptive axiom set is needed. Although *SIGGS* was fairly comprehensive, there was no attempt to analyze the 201 hypotheses for consistency nor to finalize an axiom set that would be the underlying axioms for a GST. Thompson has since been developing Axiomatic Theories of Intentional Systems (*ATIS*), which is a logico-mathematical theory model for analyzing and predicting behavior of systems that are goal-directed or intentional. Using the original *SIGGS* hypotheses, Thompson developed a nomenclature to define system properties, which improved the precision with which *SIGGS* properties could be used (Thompson, 2005). Thompson also identified an initial list of approximately 100 axioms (subject to change, as this work is on-going), and extended the 73 SIGGS general system properties to 136 in *ATIS* (*APT&C* Website, 2005).

Using General System Properties to Describe an Educational System

Following are a few examples of the basic, structural and dynamic properties formulated in *ATIS* as applied to educational systems. For greater detail, the reader is referred to extensive reports by Thompson (*APT&C* Website, 2005): http://www.indiana.edu/~aptfrick/reports/ .

Basic Properties

Basic properties define the initial attributes required to identify and analyze a system. In *ATIS*, there are only three Basic properties—complexness, general system state, and size. For example, a system consists of at least two components that are connected by an affect relation. Understood in the context of an education system, one example would be teachers and students, who are components that are connected together by a 'guidance of learning' affect relationship. These affect relations determine the complexness of the system. The formal definition and logico-mathematical typology of 'complexness' is:

Complexness, $\mathcal{X}(\mathbb{S})$, $=_{df}$ the connectedness of an affect relation.

$$\mathcal{X}(\mathbb{S}) =_{df} (\mathcal{A}_m \in \mathcal{A}) \mid (x, y) \in \mathcal{A}_m \supset x \in {}_C\mathcal{C}$$

Complexness is measured by the number of connections.

Structural Properties

'Strongness' is an example of a structural property that describes relationships between system components. 'Strongness' is defined formally:

Strong system (strongness), ${}_S\mathbb{S}$, $=_{df}$ a system with affect relation sets characterized by strongly connected components.

$${}_S\mathbb{S} =_{df} \mathbb{S} \mid \exists \mathcal{A}_i({}_S\mathcal{C})$$

'Strongly connected components' means that all components in the affect relation set are connected to each other, but at least one of the connections is unilateral (one or more is not bi-directional; otherwise the components would be completely connected).

Assume that we are examining the affect relation 'guidance of learning' in a classroom. If classroom instruction is solely from the teacher; e.g., demonstrating, explaining, questioning, prompting, and evaluating student responses, then such 'guidance of learning' is defined by the unilateral connectedness from the teacher to the students. Strongness can be increased if there were more connections between system components. For example, when students work in project groups, 'guidance of learning' connections can be created among students as they share what they know with each other. Such affect relations become 'completely connected' when all of them have bi-directional connections with each other. 'Completely connected' components are defined formally:

Completely connected components set, ${}_{CC}\mathcal{C}$, $=_{df}$ a set of system components that are pair-wise path-connected in both directions.

$${}_{CC}\mathcal{C} =_{df} \mathfrak{X} = \{x \mid x \in \mathfrak{R} \subset \mathbb{S}_0 \wedge \exists y \in \mathfrak{R}[x \neq y \wedge (x, y) \in {}_{cc}E]\}$$

Dynamic Properties

‘Adaptableness’ is an example of a dynamic property that describes how the relationship between system components changes over time. It is defined formally:

Adaptable system (adaptableness), ${}_{A}\mathbb{S}$, $=_{df}$ a system compatibility change within certain limits to maintain stability under system environmental change.

$${}_{A}\mathbb{S} =_{df} \Delta\mathbb{S}'_{t(1),t(2)} \Vdash \Delta\,\mathscr{C}_{t(1),t(2)} < \alpha \Vdash {}_{SB}\mathbb{S}_{t(1),t(2)}$$

For example, a school system has high adaptability if its graduation rates do not vary significantly when the standards for passing state examinations are raised. ‘Filtration’ is another example of a dynamic property. It describes the criteria a system uses to determine which toput qualifies as input to the system. The criteria for selecting its applicants act as a filter for entry to the school (e.g. students who are less than 5 years old are typically not allowed to enter K-12 schools). ‘Filtration’ is defined formally:

Filtration, $\mathscr{F}(\mathbb{S})$, $=_{df}$ the set of *toput system-control qualifiers* that control *feedin* of *toput*.

$$\mathscr{F}(\mathbb{S}) =_{df} \{P(x) \mid P(x) \in {}_{T_{\mathcal{P}}}\mathscr{L}_{C} \wedge A^{\mathcal{F}iltration}\sigma_{x}\,(\sigma_{x}: T_{\mathcal{P}} \times {}_{T_{\mathcal{P}}}\mathscr{L}_{C} \rightarrow (T_{\mathcal{P}}, I_{\mathcal{P}}))$$

This is Getting Pretty Technical—How can It Be Managed?

The busy education professional may wonder, “Do I have to be a mathematician to benefit from these concepts in my work?” The short answer is: No, you don’t have to. We don’t have to be engineers to drive our cars or use our microwave ovens. We can use devices built on scientific theories without knowing all the details.

ATIS is quite complex and very detailed. It is difficult, even for the present authors, to keep track of all the detail. This is where we believe that computer technology can help us. We are building a software simulation, called *PESO*: Predicting Education System Outcomes. *PESO* will keep track of all the details, allowing us to focus on the predictions.

How *PESO* Makes Logic-based Predictions

Even though there are over 200 axioms and theorems in ATIS as of this writing (APT&C Website, 2005), only 5 axioms apply under the condition: input decreases. Axioms 10, 11 and 13 predict thee outcomes of decreasing input. However, Axiom 11 predicts a decrease in storeput, which triggers Axiom 16. Similarly, Axiom 13 triggers Axiom 28. This kind of chaining illustrates how the inference engine that is built into *PESO* works. *PESO* actualizes the logical implication of transitivity – e.g., if A implies B, and if B implies C, then A implies C.

PESO will carry out the implications, as illustrated in Figures 1-8 above. First, the user must enter the specific conditions that currently exist for a particular school system or district. *PESO* then finds all the relevant axioms and theorems from *ATIS* and uses them to make predictions about this particular system—not other systems, not all systems, but *this* system under these conditions.

How will you know, for example, whether input is increasing, flexibility is decreasing, or filtration is increasing in your particular education system? You will need to *measure* these system properties. This means you will need to observe, collect data, and/or use existing data about your education system. You will be able to use *APT&C* software to assist in the data collection and analysis. This will help you identify the temporal and structural patterns in your education system, and it will do the calculations for you.

***SimEd Technologies* Will Include *APT&C* Software**

Analysis of Patterns in Time and Configuration, *APT&C,* is a different kind of measurement paradigm. *APT&C* is a mixed-mode research methodology and software tool to help create knowledge of education systems that is directly linked to practices and changes in practices. *APT&C* bridges the gap between traditional linear models in quantitative research and qualitative research findings that lack generalizability (Frick, 1990; 2005). *APT&C* builds on work done by Frick (1990) on *APT* and by Thompson (2005).

APT&C is different from the widely used Statistical Package for the Social Sciences. *SPSS* uses the traditional approach to measurement and statistics that requires you to measure things *separately*, and enter numbers for each variable such as a student's test score, age or grade in school. Then you analyze the data by using statistics such as correlation, analysis of variance, regression analysis, etc. This is referred to as a linear models approach by statisticians. Linear models statistically *relate separate measures* of things.

In contrast, *APT&C* directly *measures the relation*. The difference is significant. In the linear models approach, you will get an r value or the results of an F test, for example, to tell you whether a relation between or among measures is statistically significant. In *APT&C* you will get different kinds of values which are measures of temporal or structural patterns. For example, you could predict student engagement when direct instruction is or is not occurring as Frick (1990) did. He found that students were 13 times more likely to be off-task when direct instruction was not occurring during academic activities. This is a temporal pattern. In his study, students were observed to be engaged about 97 percent of the time during direct instruction, but only 57 percent of the time during non-direct instruction. These percentages are measures of the temporal relation, and are based on probability theory and set theory.

This kind of *APT&C* finding is similar to epidemiological findings in medicine. For example, heavy cigarette smokers are 5-10 times more likely to have lung cancer later in their lives (Kumar, et al., 2005), and, if they quit smoking, the likelihood decreases. While causal conclusions cannot be made in the absence of controlled experiments, nonetheless one can make practical decisions based on such epidemiological evidence. You can do likewise with *APT&C*. The practical conclusion of Frick's study is that direct instruction engages students. If a teacher wants students to learn, direct instruction is more likely to produce student engagement.

In addition to temporal properties, *APT&C* will allow you to measure structural properties of educational systems. Examples of structural properties were listed in Figures 1-8 above, such as *strongness* and *flexibility.* You will enter data into what are called 'affect relation matrices' to indicate the structure or configuration of your educational system. Then the software will "crunch the numbers" and provide the values for properties such as strongness and flexibility. This is how you will determine whether *strongness* or *flexibility* is increasing or decreasing over some period of time.

Once you have measured and analyzed these dynamic and structural patterns in your education system, then you can identify the specific conditions that exist regarding those property values of your educational system. You use the *PESO* program to then make predictions of educational outcomes for your system under these specific conditions. If, for example, strongness of instructional affect relations is *decreasing* in your system, *PESO* will apply different axioms than if it is *increasing*.

Further information on *APT&C* and additional references are found in: http://education.indiana.edu/~frick/proposals/apt&c.pdf.

Next Steps

SimEd Technologies are theories, methodologies and software tools to describe complexity in educational systems. *PESO* will need to be tried out and validated in real educational systems, whether schools or school districts, charter schools, alternative schools, or school to work programs. When it is established that *PESO* adequately describes and predicts educational system outcomes, educators can use *SimEd Technologies* to model the consequences of educational systems changes. *SimEd Technologies* will show educators all the consequences, even the unintended consequences, of changing one part of the complex educational systems they direct. Better changes and better predictions of outcomes will result.

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Word count: 5806