Linear or nonlinear? A metacognitive analysis of educational assumptions and reform efforts

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Introduction and overview

During the past nearly two decades, especially since 1983, educational reform efforts have been a hallmark of US education. As evidenced by the continuing succession of new attempts to produce more acceptable learning outcomes, and as assessed by various commentators of US education (Bobbett and Ellet, 1997; Finn and Ravitch, 1996; Fullan et al., 1998; Morrison, 1991; Schlechty, 1997; Waddook, 1995), these efforts have not been successful. Literally billions of dollars have been expended on reform efforts in the past 15 years, yet it is highly doubtful that significant increases in learning outcomes have resulted from these expenditures.

Several explanations have been put forward to explain this dismal lack of results. These include: inadequate teacher preparation programs (Allman, 1987; Fullan et al., 1998), the purpose and condition of many public schools (Finn and Ravitch, 1996; Schlechty, 1997), the lack of adequate resources (Jones and Borman, 1994), a low benchmark for standards and expectations (Finn and Ravitch, 1996), lack of parental involvement (House Select Committee on Children, Youth and Families, 1987), family and social problems (Waddook, 1995), the resistance of education to change (Morrison, 1991), and others. However, efforts to improve learning outcomes by addressing these issues have not been successful. More importantly, these reform effort failures have not led to insights or changes that would allow new and successful conceptual orientations and programs capable of resulting in significant improvements in students’ learning levels to be implemented across educational levels.

What apparently has not occurred to date in educational reform efforts is an analysis of the base assumptions and orientations from which theories and efforts for instituting these reforms have been derived. This paper addresses this problem by utilizing a metacognitive analysis of the base orientation of most, if not all, current reform efforts. It then suggests a different theoretical orientation and perspective for understanding education and attempts to improve it. By contrasting the common orientation of today and the one proposed, the paper applies this new perspective to two examples. It also examines educational reform in the light of the orientation proposed.

Metacognitive analysis

Metacognition has been defined as: the knowledge and awareness of one’s own cognitive processes and the ability to regulate, evaluate, and monitor one’s thinking. The monitoring process allows a person to more effectively control his or her cognitive processes, thereby affording more efficient and active learning (Bond et al., 1992, p. 56).

Metacognition, thus, is an evaluative and regulatory process by which patterns of thinking or behaving are examined critically to assess their usefulness in arriving at valid conclusions and/or outcomes. It requires the ability to mentally identify and evaluate the processes used to generate the assumptions, theories, and procedures as well as their interactions from which particular patterns of behavior are derived.

A metacognitive analysis of educational reform efforts is an effort to cognitively identify and critically examine educational theories and assumptions and the resulting derivatives in curricula, learning, reform efforts, and performance outcomes. A metacognitive analysis also includes such issues as school organization and
administration, teacher preparation, and other logical outgrowths of our theories and assumptions that are related to reform efforts.

At a higher level, it requires an examination of what our educational reform theories, assumptions, and guidelines, as well as some of our philosophical conjectures are based on. It is not an examination of the validity of our theories per se but rather a critical examination of the assumptions about how the world of education works that these theories are rooted in. For example, most of our educational research efforts are firmly established in reductionism. This philosophy suggests that by reducing a problem or topic to its lowest part, and studying it in detail, sufficient information will be learned to understand and predict future behaviors as well as leading to an understanding of the larger issue. This philosophy is, in part, an outgrowth of the assumption that the world, behavior, education, learning, etc. are each composed of orderly and predictable environments or parts that can be understood, predicted, and controlled through the application of scientific dissection methodology to the various parts. In addition to the use of reductionism as an assumption, such methodology also assumes that the relationship between the input and the output is proportional. A metacognitive analysis would compare and examine the results of educational intervention efforts, efforts that are embedded in such philosophical assumptions. If the results achieved from these efforts are not at the level desired, or are not understandable in terms of the theories utilized, it is usually the theories or intervention efforts that are assumed to be flawed in some manner. It is rare that the base assumptions are questioned.

A metacognitive analysis would lead further toward the understanding that current philosophical assumptions are primarily based on a linear system perspective of education wherein the expected output is proportional to the input, i.e. there is a proportional cause and effect relationship between input and output. Such an analysis should lead to the question, “what if education is not linear but rather conforms to a nonlinear system pattern of behavior?” What would this mean for our educational theories, our curricula guidelines, the way we view student learning, our reform efforts, and a host of other variables that drive the way we conduct education? Simply put, if education is a nonlinear system and we have been treating it as a linear system, then we have to re-think our entire set of educational activities, from theories to outcomes to reform efforts.

This paper contrasts linear system theory with nonlinear system theory and proposes that the nonlinear perspective is the more valid and useful. The consequences of such a revision in thinking about education cannot be over estimated. If education operates as a nonlinear system and we have been treating it and setting our goals, reform efforts, and expectations on the basis of linear theory assumptions it is no wonder that we have not achieved the results desired. Further, the application of metacognitive analysis would call for a total overhaul of education personnel preparation programs, school organization, curricula frameworks and standards, and expectations for student learning.

### Linear system theory has dominated

It is patently clear that linear theory has dominated educational theory and practice for at least this century, and probably for a much greater time. The acceptance of linear thinking has permeated educators’ thinking and determined many of their most critical decisions. For example, the decision in the early twentieth century to implement a graded classroom was propelled by the belief that children should, and do, progress in an orderly and sequential fashion from one developmental level (grade levels) to the next. This assumption of an orderly progression of development was rooted in the emergence in the late eighteenth and nineteenth centuries of a belief in the “scientific” assumption that the world could be made orderly and rational through the imposition of scientific thought and methodology. It was accepted that development progressed in an orderly (linear) fashion. It was not considered that development occurred in non-repeating, unpredictable ways, influenced by interactive events beyond the control and understanding of the observer. Deviations from an orderly progression were assumed to be an indication of some flaw or malfunction of appropriate development.

Theories and practices that have as their base a firm belief in the primacy of linear thinking have dominated twentieth century educational theory. For example, Piaget’s theory of cognitive development is a linear theory of how children develop. Perhaps the greatest harm done by a linear theory to educational improvement is Skinner’s theory...
of behaviorism. His assertion of a direct and proportional relationship between stimulus and response is a direct representation of linear thinking, omitting any chance of unpredictable variables or events to affect outcomes. Skinner’s theory of behaviorism has dominated most of education’s theories of how learning occurs and, again, is a direct result of linear thinking.

Another example of educational linear thinking affects children in the classroom daily. Most states have adopted the formation of curriculum standards and guidelines that spell out in minute detail what should be taught on a day-by-day basis. Children are expected to progress in an orderly fashion though these steps. If a child does not, the assumption is that something is wrong with the child. This is probably the greatest evil by linear thinking done to children in schools. If a child does not progress in an orderly fashion through each level specified then something must be wrong with the child. It has not been considered that children who do not progress in an orderly fashion are, in fact, behaving in an appropriate manner and that it is the linear expectation of orderly progression that is faulty.

### Nonlinear systems (chaos theory)

In the past decade or so, nonlinear dynamical system theory has increasingly been applied to the social sciences (Gregersen and Sailer, 1993). Recent applications have included family therapy (Butz et al., 1997), learning (Ennis, 1992), psychology (Duke, 1994), developmental psychology (Bogartz, 1994), and psychological assessment (Heiby, 1996). Guess and Sailer (1995) have developed implications of chaos theory to human behavior in general and special education specifically.

There has also been a recent increase in the number of articles relating nonlinear system theory to a variety of educational topics and issues. These include discussions that address educational reform efforts (Snyder et al., 1995; Garmston and Wellman, 1993; Wertheimer and Zinga, 1997). Other educational issues addressed by this theory include teacher education (Benson and Hunter, 1993), although these authors argue against chaos theory as valid in teacher education. Still other educational areas include educational administration (Blair, 1993), learning (Reilly, 1998; Trygestad, 1997), educational research (Bobner et al., 1989; Lindsay, 1989), teaching and learning (Loree and Stupka, 1993), instructional design systems (You, 1993), reading research, (Robinson and Yaden, 1993), and curriculum theory (Iseke-Barnes, 1997).

One of the difficulties in examining educational systems is that at various times, and depending on the circumstances, they can demonstrate the characteristics of either a linear or nonlinear system. Because a continuum exists between linear and nonlinear behavior, educational systems, as well as children and other systems, may also operate at one of two points between these end points. Nonlinear theory provides a conceptual framework for understanding educational system behavior and development efforts and children’s behavior and learning patterns as well as educational change efforts. Nonlinear dynamical system theory has sometimes been described as chaos theory (Gleick, 1987), complexity theory (Butz et al., 1997), catastrophe theory, (Brown, 1995), and others. What is clear is that dynamical nonlinear systems have certain important characteristics and can be differentiated from linear systems along several dimensions.

### Linear and nonlinear system differences

Nonlinear systems differ from linear systems along many dimensions (Brown, 1995), several of which are critical for understanding educational system functions. These critical differences are indicated in Figure 1.

The dimension of initial conditions is a critical difference between linear and nonlinear systems. In linear systems, initial differences are not important and are not predicted to lead to significant effects on final outcomes. Sensitivity to initial conditions in nonlinear systems is often referred to as the “butterfly effect.” It holds that even seemingly minor disturbances in the initial conditions of a system can have a substantial and significant effect on later attributes and performances of the system. This suggests that if two systems or children are beginning a process of development or change from a previous condition, differences in the initial conditions will result in quite different and unpredictable outcomes for each. The development of each during a given time will also result in the differences being magnified because of positive feedback loops (discussed below). Thus, classrooms within a school or schools within the same district should be expected to display quite different outcomes, problems, successes, etc. even if they are provided similar resources, curricula, etc.
A second difference between linear and nonlinear systems is equilibrium. In linear systems, the drive to maintain or re-establish equilibrium after a system disruption is very strong. It is driven by the need to re-establish the stability of the system and is based on negative feedback that signals a disruption beyond acceptable limits in system functions.

Maruyama (1968) distinguished between two types of feedback as deviation-counteracting and deviation-amplifying. Deviation-counteracting (negative feedback) is a linear system function designed to bring the system back into a state of equilibrium. In nonlinear systems, deviation-amplifying feedback (positive) amplifies the difference between the original state of the system and its condition caused by disruption. The state of the system after this amplification becomes the system condition in an ongoing process to which further positive feedback adds to the distance and difference from the original state of the system until it assumes the characteristics of a chaotic state. As Cutright (1996) pointed out, this type of feedback becomes part of the cause in subsequent repetitions of the pattern. It is important to note that a nonlinear system can, under certain conditions, re-organize itself into a new system state that is able to adapt to its surroundings in new and presumably more productive ways.

Third, in linear systems prediction is deterministic. The purpose of prediction is control of the physical environment. When one is able to predict outcomes one is able to control the variables and processes that produce the outcome desired. In nonlinear systems, results occur by chance and are not predictable. Whereas linear systems deal with order, regularity and predictability, nonlinear systems deal with disorder, irregularity, unpredictability and chaos. Nonlinear systems may be deterministic and some authors believe that there is an underlying though highly complex pattern to the behavior evidenced even by systems in chaos. Chance seems to play a more critical role in determining how a system will react to a particular set of conditions, however. Minute factors in a lower level of a system can have substantial effects on system components quite removed from the initial disturbance. This is why it is critical to identify the various system components and where they intersect. Thus, in educational development efforts where the final state of affairs is not predictable, the outcomes may well hinge on minor events whose influences on the development process are out of proportion to their status. Prediction is uncertain because the output of the system is not proportional to the input. For example, Jones (1992) comments on the significant investments in new technologies that have not produced the expected productivity gains. The outcomes have been much less then the amount of the input.

A fourth and very critical difference for the purposes of this paper is that feedback is negative in linear systems. The purpose of negative feedback is to alert the system that something is beyond acceptable limits and corrective action must be undertaken to re-establish the stability of the system. In nonlinear systems, feedback is positive. Positive feedback is the mechanism that serves on a continuing basis to actuate the difference between an initial condition of a system and a resulting one. Thus, a system in a chaotic state is one that is in an end process of change, a condition that uses the change process to extend the differences from the initial condition of the system. This difference may also provide the basis for forming a new system organization and set of operating parameters. Thus, such change and development should be expected and under conditions where more effective system outcomes are desired should be expected, assisted, and nurtured.

The last difference between these types of systems is that the philosophical base for linear systems is reductionism. That is, systems, whether physical, behavioral, or other, can best be understood by reducing the phenomenon under scrutiny to its lowest element and studying it in detail. In nonlinear systems, the philosophical base is creativity and expansion. This means that the system is best understood in terms of the inter-relationships among its various components. In fact, a system can only be understood in terms of these relationships for it is the interactions that give the system definition and meaning. As Wertheimer and

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**Figure 1**

Critical differences between linear and nonlinear systems

<table>
<thead>
<tr>
<th>Linear</th>
<th>Nonlinear</th>
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<tbody>
<tr>
<td>Initial Conditions</td>
<td>Not Important</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Stability</td>
</tr>
<tr>
<td>Prediction</td>
<td>Deterministic</td>
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<tr>
<td>Feedback</td>
<td>Negative</td>
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<tr>
<td>Philosophy</td>
<td>Reductionism</td>
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Zinga (1997) point out, one value of applying nonlinear theory to school reform efforts is that it offers a holistic perspective for examining complex systems. By isolating one component of the system to study in detail, the relationships among components are lost, as are the meaning and understanding of the system. This suggests that isolating one element of an educational system (e.g. curriculum development) to alter may lead to unexpected changes in other parts of the system (e.g. teacher behavior, resource allocations). This is because the inter-relations among these variables were not considered or sufficiently understood.

The differences between linear and nonlinear systems are significant. If a linear system perspective is held when, in fact, the system is operating under nonlinear conditions, misunderstanding the behavior or predicting outcomes of development efforts that are not achievable by the system can easily occur. This is likely to exacerbate problems in the reform or change process. Similarly, the same action in two apparently comparable systems may lead to quite different results. Thus, in a chaotic situation, what worked in one system may not be successful in the other.

The purpose for relating nonlinear systems theory to recent developments and changes in educational systems is to offer a more valid perspective of the types of problems, developments, and expectations currently being experienced in educational endeavors. Increasing the understanding of why current unanticipated developments and outcomes should be expected, as well as resulting in a new, more organized set of educational systems, should increase the ability of school leaders and others to enhance educational outcomes. As will be seen from the discussion below of characteristics of nonlinear systems, this perspective provides a framework for generating appropriate, realistic improvement goals as well as understanding why some efforts may result in failure. The discussion also identifies some areas for establishing new and more realistic goals and methods to achieve them.

The importance of the perspective of the type of system, linear or nonlinear, for educational development cannot be underestimated. If educational reform is a linear process then its implementation and guidance should be a straightforward management operation. The outcomes should be in direct proportional relationship to the amount of resources (human, financial, and other) invested. If, however, educational reform efforts conform to nonlinear processes then outcomes will not be proportional to the resources invested, and the actual outcomes may be quite different from those envisioned or desired.

### Characteristics of nonlinear systems

Essentially, a nonlinear system demonstrates an irregular but oscillatory pattern of behavior. There are three critical characteristics of nonlinear systems:

1. Irregular periodicity;
2. Sensitivity to initial conditions and minute changes; and
3. Lack of predictability.

These interact in a chaotic environment to produce a highly complex and constantly changing set of behaviors (Brown, 1995).

An additional characteristic of nonlinear systems is their progression of change from a linear system. There are four stages that range on a continuum from linearity and predictability through two stages of mixed linearity and nonlinearity to a final stage of chaos in which the behavior is characterized by non-repeating periodicity. Each describes a manner in which a human system, individual, educational system, etc. can behave (Merry, 1995).

The first stage is that of equilibrium, in which the intent of the system is to maintain stability. The behavior is characterized by repetition of previous behavior. These efforts are based on negative feedback and resistance to change. Depending on the extent of the disturbance and the quality of the responses the efforts may or may not be successful. The intent is to maintain the status quo and preserve the positions of power of current leaders.

The second stage is close to equilibrium where the behavior varies slightly, but predictability, from previous behavior. The goal is still to preserve the existing organizational structure and administrative leadership. The third stage, far-from-equilibrium, includes new behaviors, both predictable and non-predictable, that are developed in order to adapt to changing circumstances in different ways than had been tried previously.

The fourth stage is chaotic behavior that leads to a new, more complex organizational structure and organizational responses able to respond to changing conditions in a more adaptable manner. However, the new behaviors will be unpredictable and thus, may be the outcomes (Merry, 1995).

Another characteristic of chaotic systems, as well as of a system moving toward a chaotic state, is the notion of bifurcation.
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points. A bifurcation point is a time at which a system or system component has an opportunity to make a decision to behave in a manner that directs the system in one direction or another. Generally, either internal or external pressures, or both, have built to a level where system functions are disrupted. It is often difficult to determine which way the system will orient itself because it is not possible to determine the strength of various combinations of interacting pressures. The system first attempts behaviors that have previously re-established the stability of the system. If these efforts are not successful then the system must implement new behaviors that may lead to system stability or set it on a course toward a chaotic state. A decision to move the system in one direction, e.g. implement new behaviors, can cause a future set of behavioral interactions that would not have been encountered if the decision had been to move the system in a different direction. In turn, each of these behavioral interactions will result in a further set of behavioral interactions leading to still other behavioral interactions. Because the set of behavioral interactions cannot be predicted, it is not possible to accurately forecast future directions of the system, its behaviors, or their outcomes.

The notion of “attractors” in nonlinear systems is an important one. An attractor is the behavior that a system is attracted to or that eventually becomes the dominant behavior of the system (Briggs and Peat, 1989). There are three types of attractors that affect a system’s behavior: point attractors, limit-cycle attractors, and “strange attractors.” Point attractors act as constraints on a system’s behavior to bring it to a state of equilibrium. Limit-cycle attractors are repetitive or cyclical behaviors.

Strange attractors propel the system away from the behaviors of point or limit-cycle attractors and toward different patterns of behavior. They create unpredictability by enticing the system into non-predicted patterns. For example, an act of violence (fighting) by a non-school member on school grounds leads to a mandatory student ID system. This enrages students to the level of boycotting classes which, in turn, leads to even more restrictive rules on student dress codes and behaviors. This example points out how what could be a minor event can lead to responses that are major in their consequences.

Neither point or limit-cycle attractors allow a system to generate the new patterns of behavior that are necessary to achieve educational reform or re-structuring of the system. In educational reform efforts, the allure of “strange attractors” is resisted because the results of strange attractor behavior are unknown. Point and limit-cycle behaviors are preferred because their results are predictable, even if unsuccessful.

Each of these characteristics and stages is related to current conditions of educational systems. Together, they provide a framework for understanding the educational development, reform, and improvement efforts currently under way that are not achieving the results desired. What should be apparent from the preceding remarks is that if an educational system is in, or moving toward, a chaotic condition, its response to internal or external pressures will be unpredictable. These pressures may be either minor or major and the responses may be out of proportion to the seriousness of the pressure.

Application

Learning and curriculum development

Having been conditioned to do so, most educators probably believe that a child’s learning proceeds in a linear fashion. That is, they believe that a child’s learning capacities move in an orderly fashion from one level of development to the next in a predictable and systematic fashion. However, Reilly (1996) has demonstrated that a child’s learning may progress in an unpredictable and non-systematic pattern depending on the child’s knowledge base, his or her learning effectiveness ability, teacher effectiveness, and the rate of presentation of instructional material. Trygestad (1997) has commented that learning occurs in nonlinear ways for each learner and that small differences in the initial conditions of the learners can give rise to unpredictable results.

Likewise, curriculum frameworks and standards are based on the assumption that learning progresses in an orderly, predictable, and linear fashion. Thus, these frameworks and standards, specified by most states, assume that curriculum learning should proceed in an orderly and predictable manner, because of the assumption that learning occurs in a similar fashion. If, however, the learning level of a child is based on the factors mentioned and is susceptible to the effects of positive feedback then learning level will not be an orderly progression. Instead, the learning level on the part of a child may vary from day to day, hour to hour, and subject by subject, and this variability may be the most common learning pattern.
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For example, a student may be primarily a visual learner and do well in classes that emphasize the use of visual aids and technology delivered graphics, except for morning classes because of not having breakfast.

If learning occurs primarily as a nonlinear function then our entire approach to curriculum development, as well as the basis on which we prepare teachers, is called into question. Linear curriculum frameworks and standards that are the basis of today’s educational assessment programs may be doing a great disservice to children by assuming that learning is a linear development, when, in fact, learning does not occur in such an orderly fashion.

Teacher preparation programs

Teacher preparation programs are primarily based on the expectation that children’s learning should, and does, progress in an orderly and predictable manner. Prospective teachers are influenced to believe that, if a child does not progress in a linear fashion from one learning level to the next, there must be something wrong with the child’s learning processes. It is probably warranted to assume that it rarely occurs to teachers that it is the expectation of linear learning that is at fault, not the child’s learning pattern. If learning proceeds in a nonlinear fashion then the learning pattern displayed will not be orderly, systematic, or predictable. It will be susceptible to many influences, of which minor ones may determine the pattern of the hour.

Teacher preparation programs must instill in their students the expectation that learning will occur in a non-predictable and nonlinear fashion. Only by understanding and accepting that variability will be the norm within and among students, will teachers be able to adapt curriculum standards and expectations to the child’s learning pattern, which may vary on a daily or hourly basis. Teacher education faculty must develop new means of assisting their students understand and teach effectively to variability.

Educational reform efforts

Educational reform efforts have, for the most part, seemed to operate from a linear system expectation. That is, policy and decision makers seem to believe that if X amount of funds are expended on an educational activity the result should be X increase in student learning. For example, increasing standards for high school graduation or those for prospective teachers entering the profession at the state level are expected to result in significant and proportional increases in student learning statewide. It is unlikely that such expectations will be realized. The educational system is so complex that approaching educational reform from a reductionism philosophy and tinkering with only one variable at a time, while ignoring the effects dealing with one variable will have on other system variables as well the other complex set of interactive variables, is not likely to lead to the results desired. As Reilly (1996) has pointed out, meaningful educational reform must address the entire system of public education and educational preparation from a holistic perspective and deal with structural and interactive changes before dealing with functional elements.

It must be kept in mind that education is seeking to develop more successful means for producing enhanced learning outcomes in children while the social system in which it is embedded is itself changing at an ever increasing pace. Educational systems will display a range of behaviors from linear to nonlinear patterns. Some will be repeating behaviors that have failed in the past, such as a constant replacement of school superintendents when such replacements have not led to improved educational outcomes. Some will demonstrate a mixture of responses from formerly failed behaviors to new patterns. These responses might include removing a school superintendent while at the same time instituting a new grade level pattern in the district’s schools. Some will display the characteristics of a system in a chaotic condition. These latter systems, under both internal and external pressures to change, are attempting to develop a new structure of education, organized in new and more productive ways to successfully educate children. Various countries, including the USA, Russia, Great Britain, among others, have in various ways attempted to institute new structures and organizations of education. In the USA such efforts have included the state, e.g. New Jersey, South Carolina, taking control of specific school districts in an effort to improve educational outcomes.

Evidence from the biological sciences suggests that variability is more indicative of a healthy system than an existing linear relationship between variables would be. It is probable that the same relationships hold for the social sciences. The systems that embrace variability will be the leaders in producing educational success patterns. They are likely to organize themselves into new patterns of
design that address learning and other issues of improving education in more productive ways. They must be allowed to flourish, but only if nonlinear theory is understood is it likely that they will be allowed to continue their efforts.

**Conclusion**

These understandings of learning as a nonlinear function, as well as most functions of educational systems, including educational reform efforts, should lead to new insights and programs of educational reform. If most activities of educational systems function in a nonlinear pattern then our entire approach to setting expectations for educational system effectiveness as well as how we plan and institute educational programs and reform efforts must dramatically change. By re-conceptualizing education normality as variability, often subject to hidden, complex, interactive and unpredictable influences, we should be able to design more valid programs to improve learning outcomes.

Further, if educational systems are in a chaotic state, or moving toward such a state, it must be recognized that such a movement is not necessarily negative. It may be, in fact, a sign of a healthy system moving toward a new and more productive state. Such movements should be nurtured and not forced into trying to retreat to a previous state of functioning. Such efforts are counter-productive and probably represent most current educational reform efforts.

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Further reading

