Language Research Bulletin, 22, ICU, Tokyo

Chaos, Complexity and Language Learning

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Complex systems theory is a relatively new paradigm for understanding systems behavior. It was originally developed in the fields of mathematics and physical sciences. Complex systems theory has also been widely proposed as an important new way to look at social and cognitive sciences, including language learning. One criticism of this new paradigm in the field of language learning is that no clear model of language learning based on complex systems theory has been developed. This paper considers the current state of language education, provides an overview of complex systems theory and then proposes a basic model of language learning based on the new paradigm. The paper concludes with some implications of adopting a complex systems model of language learning.

That learning takes place is quite demonstrable, even though there are considerable differences of opinion about how to define learning (Larsen-Freeman, 1997). That teaching results in learning is much less certain. We are all aware that learning does not necessarily require teachers, and some people maintain that learning occurs *despite* our best efforts at teaching. In general, we recognize at some level that it is quite possible for us to teach but not have any learning occur as a consequence. Yet most of us continue to behave as if teaching necessarily has a direct, positive, and causal effect on our students' learning.

I would argue that one reason we have (mis)placed such importance on teachers and teaching activities in education—what the best methods are, how to order the introduction of content, how to evaluate student progress, etc.—is that these are about the only things we can truly control. What goes on inside our students' heads and hearts is obscure, messy, and clearly not under our control. Nor, for that matter, is it entirely under the students' control either. Therefore, even though learning takes place inside students' heads, we have been forced to look elsewhere to find justification for our involvement in the learning process. There have been very few people like Gattegno who advocated "the subordination of teaching to learning" (1972). We have instead focused on what the teacher could do and assumed that it would naturally cause learning to happen.

Another reason we value teaching so highly is that this view is supported by centuries of scientific tradition. It is consistent with the classical aspects of Aristotelian logic, Newtonian calculus, the development of educational method by

Petrus Ramus in the 1500's, and, more recently, the computational, information-processing models of cognition. In all of these traditions there is a cause-effect, sequential, logical, deterministic, and controllable view of the world's systems. Why should teaching and learning be any different? Perhaps they aren't, but new approaches to understanding complex cognitive processes have recently emerged that may offer a better understanding of learning. They are based on complex systems theory as well as new constructs of how the brain works. This paper will present an explanation of this new complex systems paradigm, present a model of language learning based on the new paradigm, and then look at possible implications of that new model.

Complex Systems Theory

The relatively recent science of complex or dynamic systems theory, also popularly known as chaos theory (Gleich, 1987; Kauffman, 1995; Prigogine & Stengers, 1984), has been proposed as a powerful new model for recasting and enhancing our understanding of not only aspects of physics and mathematics, but social sciences as well (Loye & Eisler, 1987). Some of these proposals have related to cognitive science in general (Port & Van Gelder, 1995) and how the brain functions in particular (Hawkins, 2004), as well as to complex social systems such as counseling psychology (Butz, 1995), public relations (Murphy, 1996), and education (Carr-Chellman, 2000; Cutright, 1997; Jonassen et al., 1997; Oekerman, 1997; Scharf & Smith, 2000). Chaos theory has also been proposed as potentially valuable in the understanding of language itself (Ellman, 1995) and in language learning and teaching (Cameron, 1999; Hill, 2003; Larsen-Freeman, 1997; Mallows, 2002; McAndrew, 1997). Probably the most complete analysis of second language acquisition from a complex systems theory perspective is provided by de Bot, Lowie & Verspoor (2005).

The main feature that characterizes complex systems is the dynamic interaction of various elements of the system over time such that the results of these interactions are not entirely predictable or proportional. A complex system, due to its dynamic and sometimes chaotic and random self-interaction, cannot be reduced to simple parts which relate to each other in very predictable ways. This doesn't mean that all complex systems behavior is entirely random. Some complex systems are more stable than others and many complex systems are governed at some level by natural constraints. As Mallows (2002) puts it:

> Chaos is now understood in an interestingly paradoxical way as order without predictability. We cannot predict individual moments in the life of a system, but the end result of its seemingly random movement is discernable order. (p. 3)

A hurricane is a good example of a complex meteorological system. Many variables are involved in the formation and ultimate dissipation of this kind of storm system. Some of the variables can have a large impact on the creation and behavior of hurricanes, such as prevailing winds and ocean temperatures; other variables can have less impact, like the effect of a small island that the storm passes over. However, no one knows what effect even the seemingly smallest influence can have on this kind of system. The idea that most poetically captures this uncertainty about what impact variables may have on a complex system is the "butterfly effect" in which it is theorized that the flapping of a butterfly's wings on one continent can ultimately lead to the occurrence of a hurricane half way around the world (Gleich, 1987). With so many variables influencing each other, and the results of those influences feeding back into the system producing new influences in a constantly changing and evolving process, it is not possible to completely predict when or where a hurricane will occur, how long it will last, or where it will go. However, there are ways to predict some aspects of even a hurricane's behavior. A given storm located in the Caribbean is most likely to move in a roughly northwesterly direction. Maybe it will go due west or due north and then curl east, but it certainly will not go straight up into space, nor will it go down into the ocean.

Complex systems, instead of being completely unfathomable, turn out to exhibit certain traits that theorists are beginning to understand more fully with the help of computers that can model complex systems (Port & Van Gelder, 1995). Some of these traits are: sensitivity to initial conditions, the occurrence of attractor states, non-linearity, and recursiveness.

Sensitivity to initial conditions means that small variations inherent in a complex system at a given point can result in large differences in the system's behavior over time. Rounding off numbers to three decimal places rather than four can produce dramatic and unpredictable results in the computer modeling of complex systems. Complex systems are also subject to perturbation and bifurcation points – sudden and dramatic shifts in system dynamics which can be caused by seemingly minor variables.

Attractor states are systemic conditions or tendencies that may emerge and remain stable over a relatively long time. A hurricane typically forms a calm "eye" at its center with the storm swirling around it. This form is a condition or state that hurricane systems are attracted to despite their otherwise chaotic and complex natures.

Non-linearity is a mathematical concept that in its full form is well beyond the scope of this paper. However, the way this term is being applied in social and cognitive sciences describes linear systems as generally sequential and predictable, whereas non-linear systems are non-sequential and non-predictable. For example, if we release a drop of water in a vacuum, it is relatively easy to calculate where it will fall and how long it will take to fall. Such calculations are linear. On the other hand, if we try to determine what will happen to a single drop of water in a hurricane, where it will fall or when, the number of variables and potential interactions among those variables make such determinations either unpredictable or unfathomable.

Recursiveness is a tendency for feedback and other variable interactions to cause loops within sub systems of a complex system. These loops may persist for awhile before they phase into a new pattern. In this manner, wind or rain cells can form within a hurricane and move in different directions from the main storm for a while and then disappear or change into a different configuration.

As mentioned earlier, increased understanding of complex systems and their underlying traits has led a number of researchers and scholars to advocate the application of complex systems theory to fields beyond mathematics and physical science, including language learning. However, despite these enthusiastic recommendations, so far relatively little has been done to actually apply principles of complex systems theory in the areas of psycholinguistic and language education research. Reasons for this may include misapprehension regarding the nature of complex systems theory as ultimately nihilistic (Trygestad, 1997), inappropriate attempts to use chaos theory to solve problems framed as linear and non-complex (Paulson, 2005), or the lack of an established model of language learning derived from complex systems theory on which to base research (Hunter & Benson, 1997). Swan in particular points out the problems inherent in transforming a theory designed for physics into a loose metaphor for behavioral and social sciences (2004).

In summary, if researchers and practitioners in psycholinguistics and language learning want to fully examine the value of complex systems theory, we will need a practical model of language learning based on complex systems theory as well as research questions and methods consistent with such a model. The purpose of this paper is to address this situation by presenting a basic model of language learning which is derived from, and consistent with, the principles of complex systems theory, and to then examine some of the implications of this model.

Language Learning as a Complex System

Almost all science from the revolutionary work of Leibnitz and Newton in the 17th century up to the relatively recent advent of computers was based on the ability to solve linear problems. Since non-linear problems could not be solved (before computers came along), scientists worked on linear problems by putting them into the form of an equation and then tried to solve that equation. This has led to many advances in all fields of science, but it also left many non-linear questions unexplored. However, following the lead of Sir Isaac Newton, many problems which were known to be inherently non-linear have been twisted into pseudo-linear perspectives to produce approximate solutions. According to some cognitive scientists, one result of this Newtonian scientific tradition was the misapplication of a linear, computational model rather than the more appropriate non-linear, dynamic model to the understanding of cognitive processes (Port & Van Gelder, 1995). In opposition to this view, Swan (2004) has commented that:

> There is a tendency in such discussions to use the words ‘linear’ and ‘Newtonian’ in a derogatory sense, as if they related to discredited and invalid modes of thinking. This is misleading and unhelpful. (p. 68)

Swan is quite correct in suggesting that linear and Newtonian models of science have been, and still are, completely valid, effective, and appropriate for conducting many kinds of scientific inquiry. However, this does not mean that they are appropriate or effective for understanding all aspects of the universe. Human behavior and cognition in particular may simply not be amenable to these logical positivist principles. For example, some recent work suggests that the brain itself does not function in a linear, computational manner (Hawkins, 2004). If this is so, it seems even more likely that processes within the brain, such as learning, don't operate on this traditional model either.

Jonassen, et al. (1997) describe the traditional linear, computational paradigm as it has been applied to educational systems as follows:

- Instructional systems are closed systems, which are the sum of their parts (learners, curriculum, technology, teachers, etc.) By controlling these parts, we can regulate the performance of the whole system, which will then achieve a state of equilibrium. Instructional systems design is the process of regulating these closed systems.

- Knowledge is an external, quantifiable object that can be transmitted to and acquired by learners. The effectiveness of instructional systems, in fact, is a function of the effectiveness and efficiency of the transmission process.

- Human behavior and performance are predictable, that is, they are reliable, knowable, and predictable in known circumstances. This enables patterns of behavior to be analyzed and used to make judgments about how learners are thinking or what they have learned.

- A change in the state of one entity causes a predictable change in the state of another because of a linear relationship between the two (linear causality). Instruction predictably causes learning.

- Interventions in the learning process deterministically predict the effects of those interventions. The design of an instructional system will effect predictable changes in learners' performances. (p. 28)

They go on to conclude that:

> These assumptions over-simplify the world and reduce human learning and performance to a repertoire of manipulable behaviors. Learning is much more complex and much less certain than these assumptions infer. (p. 28)

Cziko (1999) also makes a strong case for:

> the view that complex human behavior of the type that interests educational researchers is by its nature unpredictable if not indeterminate,

> a view that raises serious questions about the validity of quantitative, experimental, positivist approach to educational research. (p. 17)

Language learning also appears to be one of these cases of a non-linear cognitive system or process which has traditionally been presented as linear so that it could be "solved" in a traditional scientific way.

The main outcomes derived from this established linear view in the case of language learning were primarily the information processing model of language use, the linguistic curriculum, and a variety of related pedagogies consistent with the kinds of instructional systems described by Jonassen et al. (1997) above.

This linear, computational model generally presents language as a finite set of grammar rules to which vocabulary items can be attached. In theory, this combination can be used by the learner to either decode or encode language. These encoding and decoding processes are generally understood as following an A + B = C process. Based on this linear, computational view of language processing, most teaching methodologies over the last century or two have been attempts to get students to learn the grammar rules and memorize vocabulary items, and then to practice formulas for encoding and decoding. Grammar translation and a variety of audio-lingual methodologies are examples of these highly linear approaches. Even with the advent of a communicative view of language, some of the early communicative approaches, which did avoid the simplicity of viewing language as just a set of grammar rules with vocabulary plugged into them, still tended to see language as finite sets of functions, notions, or lexical items and advocated that these be taught and learned in a traditional linear manner.

More recently, however, post-modern theorists have provided some new perspectives on learning that tie in with complex systems theory. Trygestad (1997) points out the compatibility of complex systems theory with the work of Dewey, Piaget, Bruner and Vygotsky and goes on to conclude:

> From a post-modernist perspective, learning is transformative. It is developed through the transformation of students' understanding rather than incrementally with students' acquisition of information. (p. 13)

In the same vein, some language education scholars such as Larsen-Freeman (1997) have drawn similar conclusions:

> Learning linguistic items is not a linear process—learners do not master one item and then move on to another. In fact, the learning curve for a single item is not linear either. (p. 151)

In Paulson's (2005) recent study of eye movements during reading he concluded:

> When viewed through the lens of chaos theory, reading can be described as a self-similar, non-linear dynamical system sensitive to reader and text characteristics throughout the process. (p. 356)

In the area of second language pedagogy, Cameron (1999) has applied complex systems theory in a study of the use of tasks in language teaching and concluded that:

> The constructs and tools of complex systems theory offer new possibilities for theorizing and researching classroom language use and learning. Tasks or activities carried out in the contingencies of real classroom contexts are more fruitfully investigated, not as a static background to performance, but as dynamic—changing and evolving in use—and, at the same time, constructing and constraining individual performance and learning. (p.1)

It appears that there is sufficient reason to take a closer look at language learning from a complex systems theory perspective. It also appears that it will be important in this process to have a new model of language learning which is consistent with complex systems theory.

Main Elements in Language Learning

In order to formulate a working model of language learning from a complex systems perspective, it will be necessary to identify, at least roughly, the aspects or elements that are involved in language learning. Unfortunately, this has the potential to be somewhat misleading, as such identification of discreet components in a system is better suited to the analysis of linear, non-dynamic systems. Therefore, it is important to bear in mind that from a complex systems point of view, the elements identified here should be understood as being in reality inseparable and without any distinct boundaries or divisions.

Engagement—feeling some desire, incentive, interest or willingness to learn; sometimes called consciousness raising. This involves a complex array of affective variables related to types of learner motivation, including intrinsic, extrinsic, integrative and instrumental. These areas of motivation are related to constructs such as identity and other socio-cultural learner variables. Engagement also includes the area of what is of personal interest or need for the learner and these interests often change over time. Another important aspect of engagement is the perceived "plausibility" of the teacher and teaching methods/materials employed (Prabhu, 1990). From a complex systems perspective, it is important to recognize the variability over time of students' affective influences and the importance that learning context variables such as teacher, materials and methods have as conditions which may perturb the learning system at anytime. The effects of these perturbations can be either positive or negative and they are difficult to control.

Noticing—detecting differences, similarities and patterns; this requires input, including feedback as input. It is debatable whether or not noticing can be done both consciously and unconsciously (Truscott, 1998), but without it learning is severely constrained, if not impossible (Skehan, 1998). Noticing is influenced by other variables including the affective "engagement" variables, as well as the sensory and cognitive skills and abilities of the learner. Variations in learning style are important in this element of the learning system. Noticing can be promoted both inductively and deductively. Noticing, like affective conditions and all other elements in a learning system, is not a constant; all of the elements phase in and out over time.

Making sense—trying to determine which differences, similarities or patterns that have been noticed are significant, meaningful or useful. This can occur either inductively or deductively. It is also influenced by affective factors which relate to what is of interest to the learner. Sense and meaning are also relative. Learners may feel that something makes sense, or is meaningful, or is correct and true, then proceed on that assumption until feedback or new information indicates another sense or a different idea of correctness. This area of recursive up-dating of what makes sense or what is meaningful and correct for the learner encompasses such things as simple performance errors and interlanguage, which are temporary phase states in the learning system. Given certain conditions, however, these attractor states can develop into more permanent fossilized errors or idiolects. Also related to making sense is the influence of L1, which can sometimes mislead the learner in terms of assigning meaning within the L2.

Organizing—sorting meaningful information into appropriate categories. This is another area where learning styles and cognitive abilities create variation and unpredictability in the learning systems of individual learners. L1 influence can also either help or hinder in this element. The ability to organize meaningful information may tend to facilitate memory.

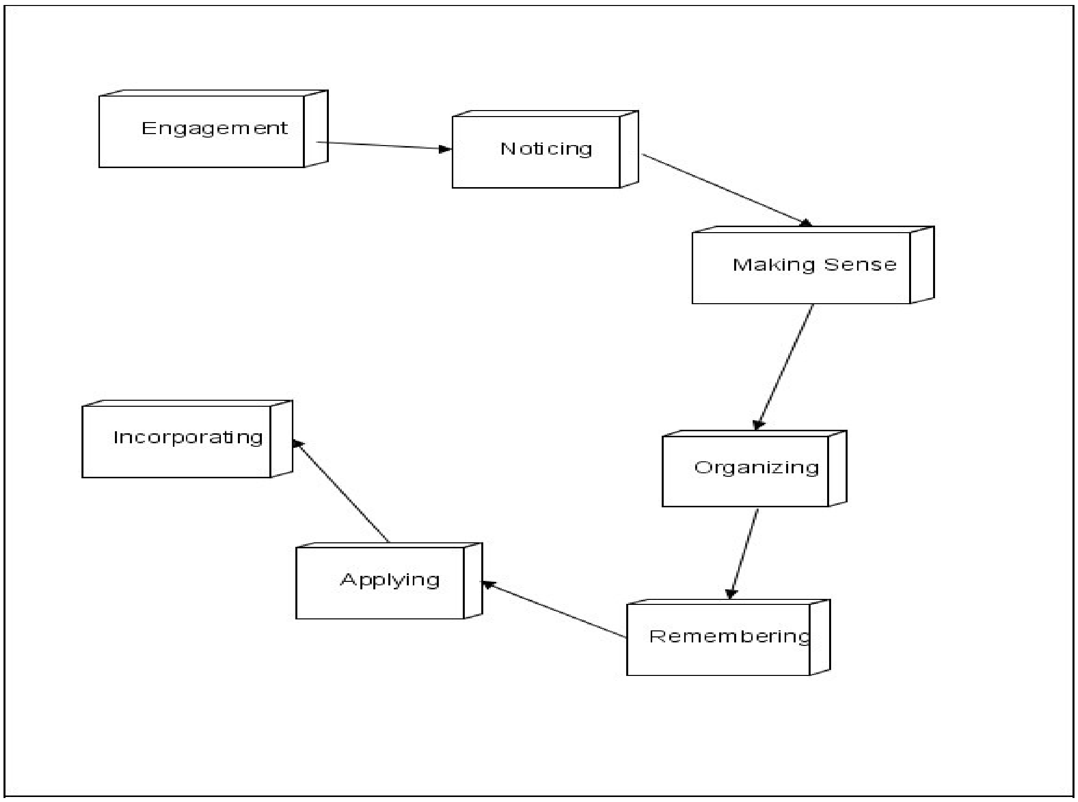
Remembering—holding onto as much of the useful or interesting information gained as possible, both in long and short term memory. In general, remembering requires recursive events or series of events to achieve a level of stability that allows application or incorporation to occur.

Applying—using the information gained for some purpose; this may or may not involve output (performance). Applying what is available in the learning system can occur in a wide variety of forms: passive or active observation of others (teacher, classmates, multimedia materials, etc.) or it can be through listening and reading. It can also be part of learner output. Output can occur at almost any time in the learning process. Rote recitation may even precede any noticing or making sense. The role and effectiveness of output as a form of applying in language learning is still debated. (Krashen, 1998; Swain, 1985)

Incorporating—making what has been learned a part of the student's identity. This element also relates to the constructs of competence (vs. performance) and automaticity (Biyalistok & Ryan, 1985; Segalowitz, 2003). After sufficient time or following sufficient motivation, learned information, skills or attitudes can become a relatively stable part of a learner's understanding of who he/she is and what he/she knows or can do.

It would be nice if these elements were followed sequentially (i.e. linearly) and once accomplished stayed accomplished. As noted earlier, that has generally been the assumption in the field of language teaching up to now. In very simple learning situations this may occasionally happen. There is, perhaps, some tendency for learning in its simplest form to follow a linear sequence like the one shown in Figure 1.

Figure 1. A Linear Model of Language Learning



In this simple model, the learner begins with a level of engagement sufficient to permit the noticing of something. Having noticed it, the learner next establishes a meaning for what has been noticed and places that meaning in an evolving organization along with other information. Given enough engagement and perhaps additional reinforcement through more opportunities for noticing, the new information remains in the memory of the learner long enough to use it in some way. If the application is effective, the information and how to use it become part of (some would say are acquired into) the learner's competence and identity.

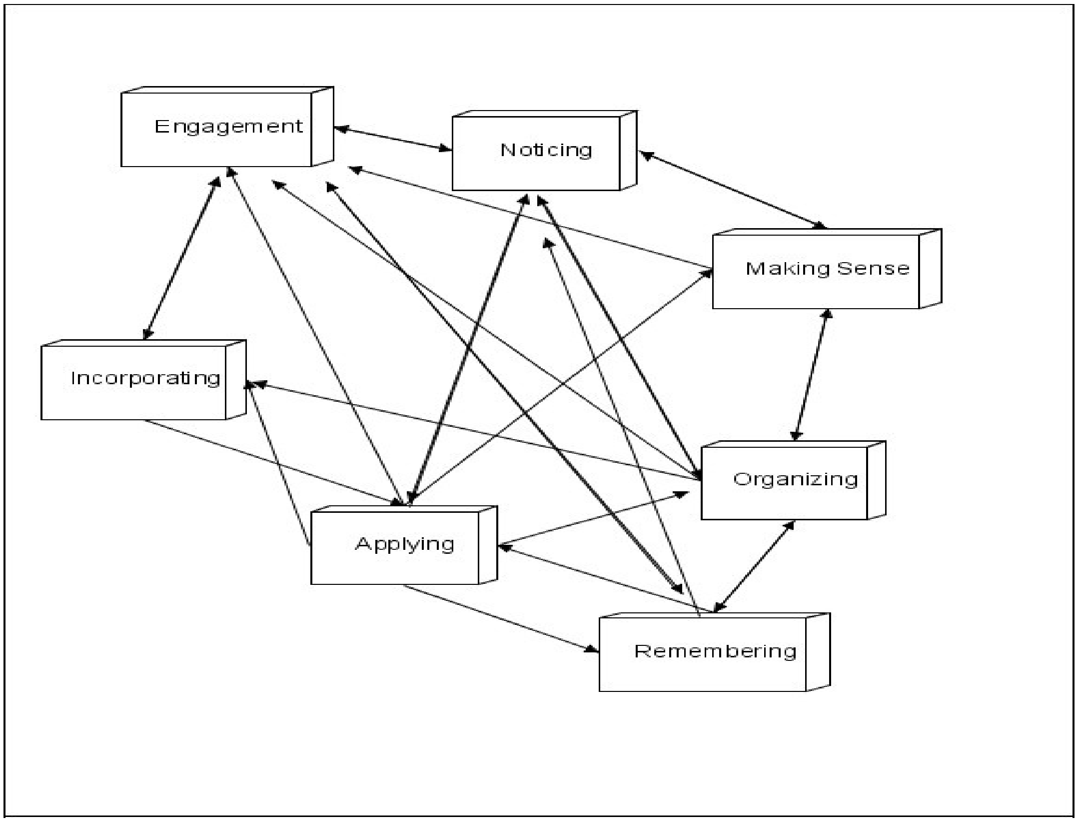
However, there is reason to believe that most of the time the learning process is far more complex than this simple linear progression. In my experience both as a language learner and observer of other learners, learning element interactions usually need to take place a number of times before they effectively lead to relatively stable states in other elements or to the learning system overall. This recursive interaction among subsystems is a significant feature of most complex systems. As a result, there are constant and either unpredictable or unfathomable loops among these elements within the learning process of each student (Port and Van Gelder, 1995). In addition, there are no natural divisions or end points in the overall learning process; it is continuous but erratic and the target is a moving one (Larsen-Freeman, 1997). On the other hand, as with many complex systems, there appear to be attractor states which help shape and guide developments in learning over time. Thus, a slightly more realistic model of learning would look something like the one shown in Figure 2.

In this dynamic model of language learning, each element is a complex system in its own right. For example, engagement involves a wide range of variables which interact and change in unpredictable ways. This sub system is influenced by feedback and has variations in stability related to its own attractor states. In some learning contexts, for example, demonstrating competence in the L2 may have negative social consequences and thus poor performance persists as an attractor state related to socially derived feedback on the learner's identity.

Each of the subsystems or elements can interact with any or all of the others, again going through different phases and degrees of stability. There are recursive loops among different elements and the occurrence of bifurcation points. For example, information may reach a bifurcation point that determines whether or not it will move from short term memory to long term memory. If the information is lost from memory, it will need to be noticed again before it can be reassigned meaning and a place in the learner's organization of information. The action of applying information can have an influence on the stability of the meaning of the information by confirming or disconfirming the meaning assigned by the learner. If the application disconfirms the meaning, the learner may revise the meaning and try applying it again, or may forget about it until further noticing or engagement factors bring it up again.

Other complex systems theory factors that influence learning systems include feedback and stability. Feedback can occur at any point within the complex interactions of the other elements. This feedback can either promote or inhibit the learning process. The occurrence of stability or instability in systems is also significant. Stability is related to the influence of attractors or attractor states on one hand and injections of new information or other perturbations in the system on the other. For example, learners may be attracted to relatively regular grammatical forms and use them more frequently than less regular forms. This overuse of regular forms may persist as a relatively stable phase state in the learning system until such time as the learner develops sufficient confidence in the use of irregular forms (de Bot, Lowie & Verspoor, 2005).

Figure 2. A Dynamic Model of Language Learning



Unfortunately, the true complexity of a dynamic learning system cannot be effectively represented by even the most sophisticated of graphics. The diagram in Figure 2 only begins to hint at how non-linear and complex the system is. It also gives a false impression of the elements as being distinct and static. The main attributes of this model of language learning are:

1. It is non-linear. Learning proceeds in an erratic, recursive and dynamic fashion, although normally there is a trend over time toward greater stability of information, skills and attitudes formed by the learning process.
2. It has limited predictability. There is a general directionality to the overall learning process and certain attractor states can be anticipated at various points in time, but specific learning achievements can only be determined partially and temporarily.

3. It is subject to many variables that have complex interactions.
4. It is difficult to control. Direct cause and effect control mechanisms rarely produce fixed, reproducible results.
5. It is susceptible to influences and contextual conditions. However, the exact extent and results that these influences and conditions have on the learning system are generally not directly observable or measurable.
6. It is generally unfathomable. Our only insights into what is going on—observed behaviors and test results—are at best indirect, partial and temporary.

Summary

Language learning, like other cognitive processes, appears to be a complex, dynamic and to some degree chaotic process which is not amenable to direct observation or control. It is subject to myriad variables and influences, many of which we—both students and teachers—are not aware of and over which we have limited control.

Some critics of a complex systems view of language learning conclude that if learning is so chaotic and unpredictable, it means that teaching must therefore be pointless (Benson & Hunter, 1993). However, I believe that that reaction is too simplistic. Complex systems are difficult to control, but they are subject to influences. The exact impact of these influences cannot be predicted, but general trends can be expected over time. A hurricane is a complex system that can't be directly controlled, but contextual influences such as prevailing winds and temperature differentials over land and water produce tendencies (attractor states) that guide these storms to move and develop in roughly predictable ways. Predictions of complex systems and ways to influence such systems' outcomes are also getting better as more is learned about complex systems behavior.

Implications of a Complex Systems Model

> *Before enlightenment, chop wood, carry water. After enlightenment, chop wood, carry water.* — Zen saying.

The difference between a traditional linear model and a dynamic systems model may not at first glance appear to imply much change in educational systems or teacher behavior. Students still need to be encouraged, provided input, given explanations, tasks and feedback. Schools will still require grades, attendance records, and other assessments. However, "enlightenment" vis-à-vis the complex, dynamic nature of learning should lead to deeper understanding and more effective learning over time. Adopting a dynamic systems model of learning will support and promote several fundamental changes in education:

***Emphasis on individual learning processes*.** Rather than imposing rigid and standardized one-size-fits-all pedagogy and materials, educators and educational programs will focus on providing an input-rich environment combined with varied, interesting and engaging activities that promote individual learning. Use of internet based resources in particular can be helpful in encouraging students to explore materials that are relevant to their unique interests and needs.

Teachers as resources and models. Rather than seeing teacher behavior as a direct causal element in students' learning, we will see teachers as resources and models. We will also reject the traditional view of teaching as transmission of information that can be banked for some time in the future when it might be needed. Instead, we will have systems that encourage students to strengthen their own learning abilities by having learning modeled for them and by encouraging learning that has as much current meaning for the students as possible.

Holistic engagement levels and proficiency change over time as the basis for program, teacher and student assessment. Measurement of learning outcomes will be based on a relatively long-term scale with interim sampling that would provide indirect assessment of learning trends within groups of students rather than trying to determine that a sequence of discrete, fixed achievements has taken place in individual students.

In addition, measurement of factors such as engagement and effort may be the best indicators of how likely it is that learning is taking place, and consequently the effectiveness of the educational system/environment. These could be in the form of activity parameters such as how much reading students do, how extensive their journal entries are, how much they participate in class, how many exercises they have completed, etc. They could also be in the form of self-report on how motivated students feel and how interesting the material is to them.

Conclusion

Changing any idea that has been generally accepted for centuries is never easy, as Copernicus and Galileo found out. The same will most likely be true with changing our fundamental concepts of learning and education. But perhaps it won't be too difficult. I think the seeds of this transition are already planted. Concepts like student-centered education, the existence of multiple intelligences, different learning styles, and the value of content/task/problem-based instruction are not entirely foreign now and they appear to be better suited to a dynamic systems model of learning than the traditional linear one. Furthermore, the increased use of computers in education will allow greater exploration and incorporation of non-linear materials to support learning.

None of the elements in the complex model presented here is in itself inimical to any particular technique, method or approach to language teaching. What combinations will work best will depend on the learning context, the nature and interests of the learners and the beliefs and skills of the teacher. This is to some degree in line with the emerging notion of local pedagogy. In fact, a complex systems theory perspective on language learning supports all methods and approaches as potentially beneficial depending on context and how flexibly they are used.

Another concept that emerges from this complex systems perspective is that what we have seen as either/or issues under a linear, computational view of language learning are not necessarily that simple. Language learning is complex enough to encompass rather than force a choice between acquisition and learning, process and product, input and output, grammaticalized lexis and lexicalized grammar, etc. Language learning is also complex enough that learners may (at times) benefit from deductive, drill-based learning as well as inductive, task-based activities. Learning and learners are not amenable to a best method, a best book, a best test, or a best curriculum. Learners are most amenable to influences that recognize, respond to, and nurture their truly complex and dynamic learning processes.

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