# The Dynamics of General Developmental Mechanisms: From Piaget and Vygotsky to Dynamic Systems Models

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*Abstract*

Dynamic systems theory conceives of development as a self-organizational process. Both complexity and order emerge as a product of elementary principles of interaction between components involved in the developmental process. This article presents a dynamic systems model based on a general dual developmental mechanism, adapted from Piaget and Vygotsky. The mechanism consists of a conservative force, further strengthening the already-consolidated level, and a progressive force, consolidating internal contents and procedures at more advanced levels. It is argued that this dual mechanism constitutes one of the few basic laws of learning and change, and is comparable to the laws of effect and of contiguity. Simulation studies suggest that this dual mechanism explains self-organization in developmental paths, including the emergence of discrete jumps from one equilibrium level to another, S-shaped growth, and the occurrence of co-existing levels.

*Keywords*

development; dynamic systems; developmental trajectories; Piaget; Vygotsky

If a contractor builds a house, the combination of masonry, woodwork, and whatever else is involved in such a task is governed by a building plan that prescribes the sequence of building actions and materials that finally lead to the finished house. If houses emerged by self-organization, stones would automatically attract other stones and cement, wood, and other construction elements to form houses that are automatically adapted to the wishes of their inhabitants. It is clear that houses are not built like that, but dynamic systems theory claims that developmental processes are considerably closer to the self-assembling house than to the house built under supervision.

## DYNAMIC SYSTEMS THEORY: GENERAL PRINCIPLES

Dynamic systems theory is antireductionistic in that it allows us to select a level of description and explanation and take for granted whatever precedes that level. Once this level of description has been selected, we try to show by what principles its components self-organize into the processes and structures of interest. Typically, a dynamic systems model consists of a minimal number of variable components that interact in accordance with specific principles. In a recently published model, for instance, I simplified developmental processes that occur to a person by reducing them to one-dimensional change, that is, change in a single variable (van Geert, 1998). The variable may be a particular skill or an aspect of knowledge, such as a child's knowledge of the lexicon of his or her mother tongue. It may also be an overall measure of developmental change, defined over several variables (e.g., a general level of linguistic skill, which comprises lexical, grammatical, and phonological knowledge and skills). In principle, developmental change means progress, but the model also allows for regressions. For instance, a particular skill or group of skills may show a temporary decline that might introduce a jump toward a higher level. The model simulates an environment that is equally simplified: Whatever the environment does amounts to either increasing or decreasing the level of the modeled variable in the (simulated) person. For instance, the environment may lead to an increase in a young child's lexicon. However, environmental influences may also lead to a decrease of the lexicon, such as when a native speaker of Dutch moves to an English-speaking country and loses a considerable part of his or her original vocabulary. The function of the tremendous reduction in this model is to get to the most basic principles of the phenomenon at issue (for general discussions, see, e.g., Bak, 1996; Casti, 1997; and Elman et al., 1996). It is, of course, by no means intended that development is "really" or "essentially" one-dimensional.

There are two related themes that emerge with almost every topic that dynamic systems modeling explores. One is the paradoxical relationship between simplicity and complexity; the other is self-organization. The first entails the belief that really complex phenomena, such as life-span psychological

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development, biological evolution, or the working of the brain, are in fact based on a small set of simple principles of interactive change. What makes their outcomes complex is that they apply to a multitude of components that interact across time. The second theme—self-organization—refers to the fact that the overall form of the phenomenon at issue—development, for instance—emerges from the way the components interact. It does not stem from some preestablished external or internal building plan. Self-organization, though, is not synonymous to idiosyncrasy and coincidence. Natural forms of self-organization are remarkably robust and stable. A particularly good example is the process of embryogenesis, the physical growth of embryos, which boils down to an extremely complicated self-organizational process that is nevertheless highly repetitive and relatively insensitive to many external threats.

## GENERAL DEVELOPMENTAL MECHANISMS ACCORDING TO PIAGET AND VYGOTSKY

The model I focus on in this article (van Geert, 1998) simplifies developmental processes to orderly change in a single dimension, guided by a single general developmental mechanism. The change predicted by the model is characterized by properties similar to the properties we observe in real development, such as variability and alternation between relative stability and (eventually rapid) change. The general mechanism used in the model has already been described by founding fathers of developmental psychology, such as Piaget and Vygotsky. This mechanism is probably one of the few basic "laws" of learning, comparable to the law of effect, or the principle of contingency.[2] The easiest way to explain it is to start from Piaget (1896–1980).

Basically, what Piaget claimed was that every encounter of a subject with reality—for instance, a baby reaching to and grasping a plastic block—results in a dual adaptation of the subject to that part of reality. First, it involves an assimilation of the reality encountered to the existing procedures of acting or understanding in the child: The baby grasps the plastic block and by doing so experiences the block as something-graspable-in-this-particular-way. Second, it involves an accommodation of the existing internal procedure to some of the exigencies of the reality the person is currently confronted with. There is always something new in the reality that we experience, but the nature of this novelty co-depends on what we are able to accommodate to. For instance, the baby experiences the grasped object—the block—as something that requires a particular adaptation of the position of the fingers.

A comparable dual principle was described by Vygotsky (1896–1934). He claimed that there exists a distinction between what a child can achieve when acting on his or her own (actual developmental level) and what that same child can do when helped by another person who is more competent (potential developmental level). The main point is that the actual level determines a particular form of help from a more competent person that, if indeed given to the child, helps the child achieve a result that is in advance of what he or she could accomplish independently. The components of this particular form of help are gradually incorporated into the child's own competence, thus transforming the current potential level into a future actual developmental level. Vygotsky called the range between what the child can do with help and without help the zone of proximal development (ZPD).

## A DYNAMIC SYSTEMS MODEL BASED ON GENERAL DEVELOPMENTAL MECHANISMS

In the dynamic model, an event—such as giving a baby a plastic ring—activates some internal procedure or content. This is most probably a so-called soft-assembly content: It is not something that exists in the mind in advance (e.g., an already-present representation of a circular object). Rather, it is built on the spot, so to speak, and exists as long as the activity lasts. It is the dynamic product of the interaction between the person's (the baby's) already-developed abilities and the object's properties (Thelen & Smith, 1994). The first model assumption of the dynamic model is that the mere activation of this particular internal procedure has a consolidating effect on this procedure. For instance, it increases the likelihood with which the procedure will be activated in the future. Recall that the activated procedure—the grasping in our example of a baby being given a plastic ring—specifies what is currently familiar or already known. Everything in the experienced event that deviates from the familiar is "new," and its novelty is bigger the more it deviates from the currently activated procedure (the current grasping, say). All other things being equal, the newer a content, the more interesting it is on the one hand, but, on the other hand, the less familiar it is and thus the less likely or the more difficult is its assimilation to some consolidated procedure. There exists a point where the opposing tendencies of novelty and familiarity meet and so define an optimal level of novelty: accommodatable novelty. By definition, there exists some internal procedure—of whatever nature—for processing this optimal novelty. This novelty procedure will often be one that exists by virtue of its being scaffolded or supported by a more competent other person. The second model assumption is that this novelty procedure profits from the current experience; for instance, the likelihood or ease with which this procedure will become activated in the future increases.

Finally, the model allows for a variety of inputs, that is, events that activate internal contents and procedures. The nature of the distribution of those experiences varies between a "Piagetian world," where experiences and tasks at (potentially) different levels of development are more or less randomly assigned to the child, and a "Vygotskyan world," where the experiences and tasks are carefully tuned to the child's educational needs.

In summary, in this model, a dual dynamic principle determines the effect of experiences–or activities, for that matter. First, the model contains a *conservative force* that increases the strength of whatever internal procedure is activated in a particular activity or experience. Second, it contains a *progressive force* that increases the strength of the internal procedure that falls at the intersection of novelty and familiarity as defined by the currently activated procedure.

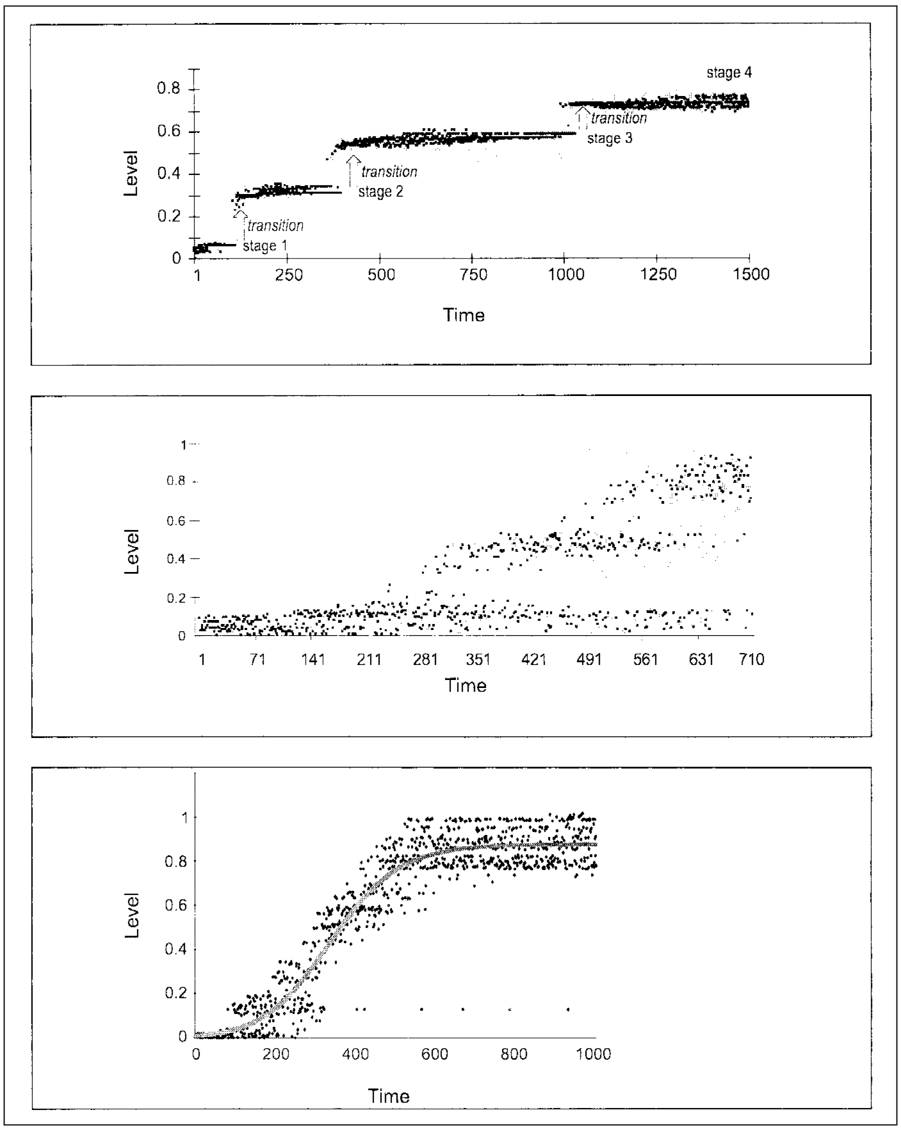


**Fig. 1.** Three outcomes of the dynamic model: stepwise change with discontinuous shifts (top panel), co-existing bands of performance levels (middle panel), and S-shaped growth (bottom panel). Dots correspond to developmental levels of (simulated) activities over the course of months or years. The gray-shaded areas correspond to coherent levels, or stages. From "A Dynamic Systems Model of Basic Developmental Mechanisms: Piaget, Vygotsky and Beyond," by P. van Geert, 1998, *Psychological Review, 105*, pp. 634–677. Copyright 1998 by the American Psychological Association. Adapted with permission.

## PHENOMENA THE DYNAMIC MODEL TRIES TO EXPLAIN

Models are built with the aim of illuminating empirical data. A model like the one presented here, which is based on general, "deep" developmental mechanisms, should in principle be able to explain the variety of empirical outcomes that is characteristic of real developmental patterns.

In the model, two variables can be manipulated. The first is the relative importance of the conservative versus the progressive forces. The second is the degree of adaptation of the environmental input to the system's current developmental level. These variables are supposed to correspond with real differences in actual developmental processes. Given these two sources of variation, the model produces a rich variety of patterns (see Fig. 1).

If both the conservative and the progressive forces are strong and the environmental input occurs more or less randomly (i.e., it is not particularly adapted to the child's current developmental level), the model produces a small number of equilibria at increasingly higher levels. The transition from one equilibrium level to another takes place in the form of a sudden jump or discontinuity, as illustrated in the top panel of Figure 1. This is more or less the situation described by Piaget: The child explores the world, and there is no particular educational monitoring involved. Piaget and the neo-Piagetian theorists claim that development occurs in the form of a small number of discrete, qualitatively distinct stages (Fischer & Bidell, 1998). This is also what the model predicts, given conditions that are similar to those postulated by Piaget, namely, that both assimilation (the conservative force in the model) and accommodation (the progressive force in the model) are important.

We can adjust the parameters so that they come in line with what we would expect from an average educational process, in which the environmental input is more carefully tuned to the child's current level and learning occurs in conditions that are set up by a tutor. Under such conditions, the model produces development along a path tending toward an S-shaped curve, as in the bottom panel of Figure 1. Such curves are characteristic of a host of learning processes in which the environmental input plays a crucial role. Note that the model works with a specific probability that the environmental input will be within a certain beneficial range around the child's current developmental level. As a result of this randomness, the model's outcomes may vary considerably, although they vary within general patterns.

There exists a competitive relationship between currently activated internal procedures and internal procedures that differ rather considerably from the activated ones. If we reduce the average magnitude of the competition, the model produces developmental paths in the form of co-existing bands at distinct levels, as illustrated in the middle panel of Figure 1. Such bands represent co-occurring, alternative strategies. For instance, when asked to spell the name of a town that sounds like "wooster," a child may apply an analogy strategy ("it sounds like *rooster* and begins with a *w*, so it's spelled 'wooster'"). The child may also have an alternative strategy that focuses on the meaning of the word. That is, the child may ask whether he or she knows a town by that name and, if so, how the name of that town was spelled (e.g., in a book the child has read). The strategies alternate in that sometimes the child uses the first and sometimes the second. The emergence and disappearance of such alternative strategies have been extensively studied in the framework of microdevelopment, an approach in which development is studied by intensively monitoring children's progress over a relatively short span of time (Siegler, 1996).

Finally, the model suggests that developmental levels—such as can be specified by various tests—are in fact ranges of varying widths instead of points on a scale (see also Fischer & Bidell, 1998). In the standard view, measurement error is said to account for the fact that an individual's level of development will vary when it is measured on different occasions. The dynamic model, however, views both the width of the child's range and the child's position on the developmental scale as characteristic properties. Interestingly, the width of the range can vary across development and increase or decrease in size (e.g., if a skill becomes increasingly automatic, it is likely that the width of the performance-level range decreases). Also, sometimes when a developing system jumps to a new level (e.g., a new and more complex way for solving problems), the old level (old way of solving those problems) does not immediately vanish, but persists for a while. This so-called bimodality (two different modes of action exist at the same time) is characteristic of developmental transitions, especially sudden developmental jumps (van der Maas & Molenaar, 1992). For instance, when a child is solving a problem, the child's verbal explanation of what he or she is doing, on the one hand, and the gestures that accompany the problem-solving process, on the other hand, may refer to different levels of understanding (Goldin-Meadow, Alibali, & Breckinridge Church, 1993).

## CONCLUSION

In discussing this dynamic model, I intended to show that it is logically possible to explain the emergence of distinct types of developmental trajectories by a process of self-organization based on general developmental mechanisms. However, we should realize that there is still a long way to go to explain how this process actually works in reality. Currently, for instance, there is a growing interest in the way genes affect behavioral development, and several domains in which the genetic influence is quite considerable have been found (e.g., general cognitive ability and forms of psychopathology, such as autism). How can such findings be reconciled with the claim that development emerges through self-organization? A similar question can be raised with regard to models that relate behavioral to brain development. Behavior geneticists and neuropsychologists, however, agree that the link between genes—or the brain, for that matter—and developing behavior is itself a highly complicated process that can probably best be understood as a dynamic, self-organizational process in which interactions with the environment play a crucial role. The question of how exactly genes, brains, and environments enter into the equations of the dynamic model is an entirely unsolved issue at the level of model building, let alone at the level of the actual empirical processes.

Although dynamic systems models of the kind discussed in this article may help us understand the nature of life-span developmental processes, they are too coarse-grained to explain the actual processes of learning, pattern formation, and information processing that take place on smaller time scales. Such processes may be successfully explained by models that take the neural organization of the brain as their starting point (so-called neural networks or connectionist models). By combining different kinds of models—in particular, models that are optimally suited for particular time scales—we may hope to come to a better understanding of the way development actually works and to go beyond simple claims about percentages of variance explained by either genes or educational factors.

We should also realize, however, that the empirical corroboration of dynamic models poses formidable problems. We need to go beyond experimental and cross-sectional approaches and also conduct longitudinal studies with dense measurements and observations. Such studies are very time-consuming and make sense only if a sufficient number of them have been carried out to allow for generalization across subjects. It is my hope that the lessons learned from dynamic systems modeling will stimulate further investments in such studies. Only a combined effort of modeling work, longitudinal investigations, and cross-sectional studies, including both experimental and observational work, will allow us to unravel the mechanisms that govern the process of development and to go beyond static connections between variables found at the level of group studies.

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## Notes

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2. The law of contingent effect states that if a behavior is immediately followed by a positive effect, or reward, that behavior is likely to occur more frequently in the future.

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