The Cambridge Companion to
PIAGET

Edited by
Ulrich Müller
University of Victoria

Jeremy I. M. Carpendale
Simon Fraser University

Leslie Smith
Freelance Researcher, Lake District, UK
The questions Piaget raised, and his concepts and observations for addressing them, have shaped virtually all research and theory in cognitive development over the last 50 years. Even those who rejected Piaget's conclusions shaped their work in terms of his questions. Some approaches built upon his work directly whereas others sought to oppose it. The focus of this chapter is primarily on the former – research and theory that has built directly on Piaget to address new, revised, and expanded questions.

The primary question raised in neo-Piagetian work is variability: the dynamic ways that people's actions differ and change. At all ages and in all cultures, people's actions vary dramatically across contexts, tasks, and emotional states. For example, in class Christina, a fifth-grade student, can read and explain a paragraph about how the eye works, but she cannot give the same explanation at home on her own. Seth, a high school freshman, can solve a math problem about the cost of schoolbooks when he does it with his mother's support, but in class the next day he is unable to solve the same problem. On the other hand, for a similar problem about the cost of new jeans, he solves it easily across all situations. This sort of variation can be frustrating, but it is normal, and it happens every day with everyone. Modern neo-Piagetian research and theory embrace this variability, using it to create better explanations of the complexity and diversity of human knowledge and action.

In this chapter we argue that the modern neo-Piagetian framework provides a solution to the long-standing problem of variability by analyzing the dynamics of the organization of action and thought. Classical explanations of development and learning often analyze action and thought in terms of static forms instead of dynamically varying structures. They explain Christina's descriptions of how the eye works in terms of her logical understanding of the mechanisms of the eye, but they do not explain how that understanding seems to disappear outside
Dynamic Development

of class. They explain Seth's variable math skill in calculating the costs
of books and jeans in terms of his knowledge of equations with algebraic
variables, but they do not explain how that skill differs across objects
and contexts.

By directly analyzing such variability in people's knowledge and
action, the modern neo-Piagetian approach explains the stability and
variability of what people know. With a focus on the dynamics of vari-
ation and stability, neo-Piagetian research and theory have built elo-
quent explanations for the richness of development and learning and
have helped reconcile long-standing tensions in the field related to
stages, developmental range, and variation in age of acquisition. Neo-
Piagetians have constructed a powerful set of concepts, methods, and
tools to ground research and theory in developmental science for years
to come. One recent but important tool of neo-Piagetian dynamic struc-
turalism is mathematical modeling, which has opened a new window
on the study of developmental phenomena.

NEO-PIAGETIAN THEORY: DYNAMIC PSYCHOLOGICAL
STRUCTURE

The broad goal of the neo-Piagetian perspective is to explain universals
in development and epistemology that Piaget so elegantly described and
to account for the pervasive variability that underpins all development
and learning. The focus of this chapter is the fundamental neo-Piagetian
postulate of psychological structure as dynamic organization. First we
explicate this argument and contrast it with the assumption of static
form embedded in traditional theories of growth and change. In develop-
mental and cognitive science, static views of structure have been the
rule, not the exception—a static property of the mind existing separately
from the behavior it organizes (Chomsky, 1957, 1965; Fodor, 1983). In
subsequent sections we show how a dynamic perspective is essential for
explaining variability.

If the search for universal structures has taught us anything, it is this:
Structures (knowledge, action, emotion) are both organized and
variable, continually changing systematically as a function of multiple
characteristics of person and context. Action in sports illustrates this
principle nicely. Even the relatively simple act of throwing a ball, for
example, is not a fixed action that happens identically every time. Con-
text matters! At a baseball game the pitcher throws differently depend-
ing on a range of factors working together: temperature, crowd noise,
fatigue, having a runner on base, and lighting (to name but a few fac-
tors). Understanding the pitcher's performance, including its natural
variability, depends on analyzing how such factors function in the immediate context, which includes the person throwing the ball, of course. This kind of dynamic process characterizes all actions and knowledge (Rose & Fischer, in press).

In classic structural explanations, structure has been confounded with form. Piaget (1968/1970) clearly stated that structure refers to the system of relations by which complex entities such as psychological activities and biological organisms are organized. In the human body, for example, the nervous system, skeletal system, and cardiovascular system all work together through constant interconnecting activity by which each system adapts dynamically to the other systems and to the functioning of the body as a whole. In the structure of a body set patterns can be detected, such as the way the nervous system creates changes in the cardiovascular system when a person experiences stress.

Piaget recognized the dynamic nature of psychological structure and believed that activity is the foundation of learning and development, but the core metaphor for stage theory (universal logic defining the developmental trajectories of each person) is profoundly static. Because stage theory equates structure [the dynamic organization of mental activity] with static form [formal logic], it does not provide a full characterization of the complex mechanisms that underpin variability and change in psychological development (Fischer & Bidell, 2006). If Piaget had an opportunity to craft his approach to cognition and development in the 21st century, we suspect he would have emphasized the dynamics of knowledge and growth.

The problem of classic concepts of structure is that they treat structure as form – an abstraction existing in its own right – instead of as dynamic organization that emerges from the components organizing themselves together. Consider an orange – a piece of fruit that has its own structure of cells and tissue that self-organizes into a spherical shape. The orange has a dynamic structure, starting with a developmental history of growth from a tree, maintaining equilibrium as a stable piece of fruit, and decaying (if it is not eaten or put to other use). In contrast to the orange itself, the concept of sphere is an abstract form that describes one characteristic of the dynamic structure – its shape – which applies across many situations. The Greek philosopher Plato (1941) suggested that these abstract, idealized forms actually exist in an arena beyond the physical world. The uniformity of the formal sphere concept makes it useful for characterizing many objects, such as balls, peaches, marbles, and planets.

Classic concepts of structure use an abstract description to characterize reality as if it were static like the concept of sphere. This form
fallacy is not limited to science: People commonly use categories in this idealized way, expecting objects, events, and people to fit such abstract concepts instead of showing the natural dynamic variation central to all living things. In social interactions, for example, people may expect others to fit the stereotype of a category, such as a wife, a scientist, an outgoing person, or a member of an ethnic minority (Greenwald et al., 2002; Rosch & Lloyd, 1978). In the same way, scientists who focus exclusively on the form of the sphere will be surprised at the differences between baseballs, basketballs, oranges, and peaches. The spherical shape of the orange specifies an abstract property that applies across different objects, not an ideal form that specifies the nature of the objects. Likewise, researchers who emphasize the role of innate forms in knowledge of number will focus on the capacity of infants to discriminate arrays with one, two, or three dots (Dehaene, 1997; Spelke, 2003) and thus will be surprised to discover that a 3-year-old does not understand the nature of numbers one, two, and three as ordered sets. The child must construct the number line to understand how numbers work in mathematics. The fallacy of form applies broadly to human behavior, from stereotypes to the nativist explanation of number.

The neo-Piagetian movement was created by scholars working to preserve many of Piaget's core epistemological assumptions (i.e., constructive knowledge, hierarchical development, structural relations between levels of knowledge) while moving beyond Piaget's most problematic concept—the assertion of universal structures of formal logic. These scholars replaced the logic model of the mind with a more dynamic, domain-specific, task-dependent, culturally embedded view of psychological structure. During the 1980s, several scholars put forward accounts of development that laid a conceptual foundation for modern neo-Piagetian research (e.g., Biggs & Collis, 1982; Case, 1985; Fischer, 1980; Halford, 1983; Pascual-Leone, 1987; Shayer, Demetriou, & Pervaz, 1988). Over the past 25 years, the neo-Piagetian framework has expanded into all areas of developmental science. It is testament to its ubiquitous influence that we cannot possibly do justice to all that is neo-Piagetian theory and research in a single chapter. Instead of chronicling the evolution of neo-Piagetian ideas or cataloging theoretical differences, we focus on the key issues of variability and stability.

To explain variability and stability together, the neo-Piagetian approach replaces traditional static views of structure with dynamic ones. Psychological structures do not exist outside of activity—like the concept of a sphere—but instead they arise from action systems embedded in what people do on a daily basis. Through the dynamic analysis of psychological structure, neo-Piagetian scholars have been able to
identify and explain specific patterns of developmental variability and have reconciled long-standing issues in the field related to stage and synchrony, developmental range, and variation in age of acquisition of knowledge.

STAGE AND SYNCHRONY: GETTING BEYOND THE CRISIS OF VARIABILITY

Piaget [1970/1983] postulated a series of stages of cognitive development, which he characterized as specific logical structures that shaped the mind, including concrete operations in childhood and formal operations in adolescence. One powerful criticism of his stage theory has been the overwhelming evidence of asynchrony in children’s development [Fischer, 1980]. Piaget predicted that as a new logic emerged in the mind, it would catalyze the whole mind into a new kind of intelligence. However, research has consistently found unevenness instead of monolithic transformation, even with logically equivalent tasks. For example, the conservation of number with items like stones or dolls is usually acquired around age 5 or 6; however, conservation of amount of liquid such as water or orange juice is not acquired until age 7 or 8 [Piaget & Inhelder, 1968/1973]. Skills for different kinds of conservation develop along separate pathways. This unevenness is difficult to reconcile with universal stages: If the mind is governed by underlying logical structures, why would they manifest themselves at one age in some contexts but not until later ages in others?

Piaget acknowledged this variability [Piaget, 1972] – which he called “décalage” – and distinguished two specific forms: He called variability in age of a given logical form “horizontal décalage,” and he called parallels across stages [logically distinct forms that share important characteristics] “vertical décalage” [Piaget, 1941]. However, although these categories of décalage may be a starting point for the study of variation, they are not in and of themselves an explanation. Defining forms of variability is not the same as explaining them. Explanation requires specifying the processes by which logical stage structures interact with environmental influences, or “resistances,” to make one kind of task develop later than another. Equally important, the explanations need to deal with the pervasive differences across individuals in developmental pathways, timing, and skill related to tasks, context, social support, and experience. In short, although stage theory offers important insight into the general shape of cognitive development, it does not explain the many kinds of variation [Fischer & Bidell, 2006].

The limitations of Piaget’s assumptions about the uniform logic behind stages were forcefully exposed when, in the 1960s and 1970s,
a large body of research began to accumulate, revealing remarkable variability in every aspect of cognitive development studied. As replication studies continued to proliferate into the 1980s and researchers continued to introduce new changes to Piaget's tasks and procedures, departures from stability predicted by stage theory proved to be the norm, not the exception. Although the evidence did not undermine the constructivism in Piaget's theory, it rendered untenable the postulate that universal forms of mental logic created stages of development. As evidence for variability became overwhelming and the failure of universal structure obvious, the field of developmental science was thrust into an explanatory crisis, which we call the Crisis of Variability (Fischer & Bidell, 2006).

One result of extensive research showing unevenness was an abandonment of the concept of stage, with many scientists and educators asserting that there were no stages but only learning sequences within limited domains, such as a sequence for the domain of conservation of number and a separate sequence for conservation of liquid. However, starting with dynamic explanations of variability and grounded in a view of structure as organization, neo-Piagetian researchers have been able to illuminate the long-standing stage debate. Arguments used to be overly simple: "Children develop in clear stages, as described by Piaget," countered by "No, they don't. Development is uneven, and there are no stages." But these arguments centered on the assumption of static forms of structure. When variation is systematically embedded into assessments and analyzed directly, both general characteristics of developmental processes and the stage-like nature of change are revealed as two sides of the same coin. In other words, the neo-Piagetian approach shifts the dialogue to determining the circumstances under which development shows stage-like properties and under which it shows continuous change.

An important characteristic of dynamic systems is that they commonly show abrupt changes, which have been variously called "reorganizations," "emergent properties," or "catastrophes" (Abraham & Shaw, 1992; van der Maas & Molenaar, 1992). Human action and knowledge grow out of dynamic systems, and dynamic models of brain functioning, cognitive development, and learning all show times of rapid, discontinuous change (Fischer & Rose, 1996; van der Maas, Verschure, & Molenaar, 1990). In other words, neo-Piagetian analysis of dynamic growth and variation demonstrates that development and learning regularly show stage-like jumps and reorganizations of action and thought. Importantly, these discontinuities appear most commonly when people perform at their highest level of skill, their optimal level. That is, for optimal level people perform the most complex skill they are capable of
for a specific task, and methods called "high support" have been devised to assess optimal level performance.

An example of a rapid, dramatic jump in performance comes from a study of the development of understanding arithmetic operations (addition, subtraction, multiplication, and division) in 9- to 20-year-olds [Fischer & Kenny, 1986]. Students did arithmetic tasks under two conditions - low support, in which they simply performed the tasks, and high support, in which key ideas needed for the tasks were primed to create optimal-level performance. The problems required explaining arithmetic operations and the relationships between them. In the low-support condition, the researcher asked the student to explain the operations and their relationships. In the high-support condition, the researcher offered prototypical answers to each problem. To offer adequate practice time and ensure optimal-level performance, the conditions were repeated 2 weeks later. For tasks shown in Figure 18.1, correct performance required that students give a truly abstract response about arithmetic relationships that went beyond a concrete answer. Instead of "addition and subtraction are related because 4 + 6 = 10 and 10 - 4 = 6," they had to explain the relationship in general terms and apply it to a concrete problem: "Addition and subtraction are related because
in addition you put numbers together, while in subtraction you take numbers apart – they are opposite operations.”

In this study, analysis of high- and low-support conditions led to a profound realization about the shapes of growth and change. Under the low-support condition [functional level] performance improved gradually and did not reach very high levels overall [see Figure 18.1], whereas the high-support condition (optimal level) produced a consistent and dramatic spurt at the age of 16. Under the high-support condition no student showed understanding of more than one abstract relationship at age 15, but all students understood a majority of the relationships at age 16. This did not happen under low support, where all students showed poor understanding.

Similar powerful spurts have been demonstrated in multiple domains and age ranges in several cultures, including reflective judgment [Kitchener, Lynch, Fischer, & Wood, 1993], moral reasoning [Dawson, 2000], self-understanding [Fischer & Kennedy, 1997], and vocabulary [Ruhland & van Geert, 1998]. Across familiar tasks, optimal-level performance spurts to higher levels at specific points in the construction of knowledge. Importantly, the modal ages of these spurts typically correspond to those Piaget posited for his four main stages (as well as additional ones), but the ages can vary across individuals, cultures, and domains. What remains constant is the place in the learning sequence where the spurts occur.

These discontinuities form a common scale for development that seems to be universal, once the dynamic variability in performance is taken into account. Table 18.1 shows this scale as a sequence of ten levels, for all of which there is extensive research evidence. A complete description of these discontinuities is presented elsewhere [Fischer & Bidell, 2006]. Note that analysis of variability in growth curves has led to reframing the stage question and resolving the stage debate. Piaget’s analysis of stages turns out to have been partly correct, but how it is correct becomes evident only within a dynamic neo-Piagetian framework.

SOCIAL SUPPORT AND DEVELOPMENTAL RANGE

The analysis of variability goes far beyond identifying when stage-like changes occur and when they do not. It forms the foundation for analyzing processes of learning and development in general. Research has made clear that people never function at a single developmental level but instead vary the levels of their actions across a broad range depending on context, bodily state, goals, and other factors. Humans adapt their skill level to the needs of the situation instead of being stuck at one level.
This range of variation is sometimes called the “developmental range” (Fischer & Bidell, 2006) and sometimes the “zone of proximal development,” a phrase from Lev Vygotsky (1978). This variation is often driven by support from other people, such as parents, teachers, and siblings, as well as by cultural tools, such as books and computers. People learn ways of acting and thinking from their culture, and support from other people and cultural tools help them become expert members of their culture.

Two main kinds of variation in the developmental range illuminate how learning, development, and enculturation occur. First, people (especially children) often perform activities with others who are more expert, thereby participating in the activity at a level of complexity they are unable to sustain on their own (Rogoff, 2003). A 3-year-old child builds a pyramid from a puzzle of interlocking blocks with his mother facilitating the process. Without his mother’s aid, he would fail miserably in his effort to build the pyramid. But with his mother unobtrusively giving him hints and supports (often subtle), he spends 40 minutes working with the blocks and succeeds in building the whole pyramid (Wood & Middleton, 1975). Similarly, a 14-year-old needs to write a 500-word essay on global warming, and her father discusses with her what her argument could be, what examples she could use, and how she can begin her argument. He supports her writing of the essay, although she actually writes almost all of it herself. Through these kinds of support,
more knowledgeable people engage closely with learners to help guide them to build skill and knowledge [Fischer & Rose, 2001].

The second kind of variation in the developmental range focuses on novel tasks or situations. When people encounter something novel that they do not understand, the most fruitful strategy for coping with it seems to be to drop down to a lower skill level – acting like a child – and explore the new situation to understand its components. For example, in one study graduate students encountered Lego robots before these gadgets had been marketed, when they had just been invented at the Media Laboratory at MIT [Fischer & Granott, 1995; Granott, Fischer, & Parziale, 2002]. With these novel, mobile objects, the students explored them through sensorimotor actions – acting in many ways like a small child, gradually building knowledge about how the robots worked. Similarly, when learning a new language, people seem to learn more effectively if they play with the sounds and grammar and thus learn the most basic elements, which is similar to the ways that babies and toddlers babble and play with speech sounds and words.

DOMAINS, SEQUENCES, AND CONSTRUCTION OF KNOWLEDGE

Beginning in the 1970s many researchers seeking to address the Crisis of Variability abandoned stage explanations altogether and opted for a framework that emphasized the domain-specific nature of knowledge. They turned atomistic, crafting a modular approach to the mind, which postulated that behavior could be divided into core domains that were themselves built on general psychological structures [Fodor, 1983; Gardner, 1983]. This domain assumption has been influential in developmental science and helped move the field beyond conceptions of monolithic universal stages. However, many domain models remain grounded in a static conception of structure, seeking a logical structure for each domain – for example, treating spatial reasoning and musical thinking as encapsulated each to itself and fundamentally separate from the other. Skills do not work that way. Action and knowledge are based on acting in the world, where there are not sharp demarcations between domains of action unless cultures create them. Babies do all sorts of actions to, say, a rattle. They grasp it, chew it, look at it, shake it, listen to it, smell it, bang it, throw it, and they try to connect the results of all those activities. Cultures, on the other hand, often establish strong demarcations between socially defined fields or disciplines, such as architecture, music performance, and history [Gardner, 1999].
The extensive research on domains has shown that many possible
domains do not actually exist as distinct cognitive entities. They do not
group together as closely related skills. For example, educators often
nominate critical thinking as an important domain, and surely critical
thinking skills play an important role in education. But describing a
kind of skill does not make it an actual domain. For critical thinking, the
skills do not cohere as a domain (Willingham, 2007). Thinking critically
about international politics, for example, does not seem to involve the
same skills as thinking critically about the physics of energy.

Neo-Piagetian research, however, has begun to uncover how knowl-
dge is built in some domains that do cohere, including development
of mathematics and literacy. We will focus on the development of
arithmetic in the early years, where researchers and educators have
discovered learning sequences for the construction of mathematical
knowledge and have shown how educators can systematically facilitate
learning based on movement through those sequences.

Case, Griffin, and their colleagues identified what they characterize
as a central conceptual structure for number in early childhood, which
shows powerful generalization across tasks (Case et al., 1996; Griffin &
Case, 1997). Infants demonstrate two kinds of simple numerical knowl-
dge, one for enumeration (one or two or three) and another for relative
magnitude (proportionate comparison of sets of objects, like many vs.
few buttons). These elementary number systems form a foundation for
understanding arithmetic, but they are not sufficient by themselves.
Children need specific experience about numbers to build the complex
knowledge foundation for understanding numbers and arithmetic.

The central conceptual structure that they have to build is an ele-
mentary number line (Figure 18.2), with numbers varying along the line,
increasing one unit at a time in one direction (two to three, or six to
seven) and decreasing in the other direction. The number line represents
a fundamental change (beyond the two infant systems) in the structure
that children have available for addressing quantitative problems, and children have to build it with numerical experience over many months. When they succeed in building the skill for the number line, that knowledge facilitates reasoning across a wide range of tasks that differ greatly except for their focus on number, such as doing arithmetic problems in school and telling time with a clock.

Many children grow up in an environment that supports learning the number line, such as their family or preschool, and they gradually construct the number line between 2 to 4 years of age. In one study researchers used simple tasks to assess children’s understanding of number, asking them to choose a particular number of objects, for example, “three dinosaurs” or “one dinosaur” [Le Corre, Van de Walle, Brannon, & Carey, 2006]. The children built the number one digit at a time. First, they understood one as a number [one and only one dinosaur] but treated other numbers as meaning “many” dinosaurs. A few months later, they added two as a number, with three and four meaning “many.” After a few more months they added three as a number, and then still later four, until finally at age 3.5 to 4 years they understood that one, two, three, and four all go together to form a number line, and the number of objects can be determined by counting. This is the beginning of the number-line framework that becomes the foundation of arithmetic and mathematics.

Case, Griffin, and their colleagues devised a curriculum for teaching the number line to young children, focusing on playing games that included the number line. Such games have been popular with children for centuries, such as Chutes and Ladders [called Snakes and Ladders in its classic form]. In these games children move objects along a number line, forward and backward, and this activity is a key part of learning the number line quickly and efficiently. Notably, as little as 10 weeks of training produced substantial improvement in number tasks that were taught – as well as in number tasks outside the curriculum [such as counting presents at a birthday party and understanding musical scales]. In contrast, training did not improve performance on non-numerical tasks such as social narratives. The power of the number-line construct is evident in both the size of the effects (explaining nearly 50 percent of the variance in performance over time – a huge effect, much larger than for most curricula) and in the fact the curriculum has been successful with children from disadvantaged communities and in multiple countries [Case et al., 1996].

So why did Case and Griffin succeed in the search for structure where others had failed? First, their concept of structure extends beyond static notions of abstract form and beyond logic: Children deal with objects
in activities organized in a framework of concepts, such as the number line. In games they play with semantic relationships between those concepts, all linked with their everyday activities. Second, Case and Griffin made use of what children actually do when counting and dealing with number and made tasks that were grounded in what the children already knew about number. Finally, an important advantage may be that the number line is built into everyday language as a basic metaphor for number, which means that children already possess key elements of the concept that they have learned implicitly through their language.

LOOKING BACKWARD: AGE VARIATION
AND THE PRECOCIOUS INFANT

An important criticism leveled against Piaget's theory was that it underestimated the competence of infants and young children (Carey & Gelman, 1991; Spelke, Breinlinger, Macomber, & Jacobson, 1992). In response to this criticism, the neo-nativist movement emerged as a theoretical alternative to Piagetian stage theory and surged forth in the 1970s to characterize many previously unknown abilities in early development within domains such as language, number, space, and object concept. Researchers who adopted this view of development have worked tirelessly to show that Piagetian tasks can mask the real abilities of children (e.g., Halford, 1989). For neo-nativists the goal is to find "essential" knowledge: to strip away the factors that limit performance as much as possible to get at the underlying competence. Over the past several decades, researchers have simplified the questions, instructions, scoring criteria, and procedural details in assessment tasks, and in the process have developed new versions of Piaget's tasks.

Take, for example, the idea of object permanence, the notion that objects continue to exist beyond what a child can perceive. Piaget used successful retrieval of a hidden object as a measure of object permanence and found it emerged in infants around 8 months (Piaget, 1937/1954). In contrast, others have used the reaction of surprise as the criterion (rather than the active search for hidden objects) and have concluded infants have this competence as early as 3 to 4 months (Spelke et al., 1992). Some researchers have used this body of evidence to argue against Piaget's major claims about knowledge development (Baillargeon, 1987).

Obviously, such discrepancies raise the question: How do we explain the origin of this early knowledge? Nativists argue that the knowledge is innate, demonstrating inborn, genetically determined competence modules. Sensorimotor limitations, they say, prevent infants from
demonstrating what they know in most experimental paradigms. This argument from precocity has been used to claim innate determination for a wide range of concepts beyond object permanence, including space, number, language, and theory of mind (Carey & Spelke, 1994; Saxe, Carey, & Kanwisher, 2004; Spelke et al., 1992).

This position fails because its argument is based on structure as form: The first glimmer of infant behavior related to a domain such as object permanence is taken to show a general competence – knowledge of the permanence of objects. Yet infants fail almost every single aspect of knowledge of object permanence. The first glimmer is only a small beginning.

The neo-Piagetian dynamic perspective puts forth a powerful, comprehensive explanation: Knowledge varies across tasks based on their complexity, familiarity, and other factors, and within a domain children develop skills in a learning sequence, an ordering of tasks along a developmental pathway. Nativist research has selectively focused on downward variation in age of onset for concepts like object permanence and has ignored the complementary and widely observed upward variation in age for other tasks and conditions (Pinard, 1981). For a theory of development to be useful, it cannot simply opt out of explaining change – explanation is required! Neo-Piagetian learning sequences describe how object permanence involves many skills arrayed along strands in a developmental web, which starts with the abilities of young infants that neo-nativists have uncovered and moves toward complex, diverse knowledge and action in the same domain. As shown in Figure 18.3, development begins with the basic knowledge of objects, space, and number, and gradually over time children build more complex knowledge along multiple strands for each domain. With number, for example, they construct the number line as their development proceeds, especially when they receive experience and instruction to facilitate their understanding.

Fortunately, research often helps resolve theoretical debates like those between nativism and Piaget: The learning sequence for understanding number described previously came from bringing together nativist and neo-Piagetian research. The nativist approach predicted that understanding the number line would spontaneously develop in young children such as 2-year-olds. However, when nativist researchers tested how young children understand numbers, their findings instead coincided with Case and Griffin’s neo-Piagetian research: Children build the number line gradually one digit at a time during the preschool years (Le Corre et al., 2006). The learning sequence for number knowledge begins with infants’ capacities for simple enumeration and relative magnitude,
but it takes several years to develop, moving through construction of the number line toward complex understanding of mathematics.

LOOKING FORWARD: MODELING DEVELOPMENT

The concepts of neo-Piagetian dynamic structuralism have influenced research and theory in development. However, concepts are not enough. To get beyond endless (and typically unproductive) arguments about vague metaphors, like whether stages exist, theoretical concepts must be grounded in explicit models capable of capturing the dynamics of growth and change. Happily such tools are now available owing to remarkable advances in dynamic systems theory and modeling in the last 50 years (Abraham & Shaw, 1992). These mathematical tools provide powerful methods to pin down processes of development and learning, allowing for a new kind of empirical theoretical psychology (van Geert, 1996), where any rigorously defined theory can be put in mathematical terms and analyzed to see what kinds of growth and other patterns it actually produces. The ability of researchers to directly experiment with theories in models moves the field toward greater sophistication and precision. In this section we offer a glimpse of the dynamic models being used
in current developmental research (Fischer & Bidell, 2006; Thelen & Smith, 2006; van Geert, 2000) and discuss ways that models can help advance the field of developmental science in the future.

At this early point in research with models, it is already clear that developmental processes demonstrate considerable variability as well as predictable points of stability. For example, in hierarchical growth a more complex structure (or skill) emerges from the coordination and differentiation of simpler structures, which is a common theme in most Piagetian and neo-Piagetian models. Figure 18.4a shows a model for four different strands (domains), each growing as a series of five hierarchically organized skills, where later skills are built on earlier ones within each strand (Fischer & Bidell, 2006). Every skill is represented by a growth function (based on the universal growth equation, which is logistic). In each domain, skills are linked hierarchically such that later skills cannot begin until earlier skills reach a specific level (just as standing is a fundamental prerequisite for walking). Across each domain, skills are connected in different ways (such as supportive vs. competitive) and at different levels of strength (from no connection to weakly connected to moderately connected). All connections can influence the shape of a particular growth function, as can the initial value and growth rate of each component. As a result, development in the model, as in real life, often shows complex patterns.
Each strand in Figure 18.4a shows clear stage-like characteristics including movement toward a common value, which is called an “attractor pattern” in dynamics. The dynamics of growth create this attractor pattern, which produces stage-like change in several domains (strands), as is evident in the graph. Interestingly, small changes to one value in the model can dramatically alter growth patterns – for example, giving rise to the spread-out trajectories in the graph in Figure 18.4b. This growth pattern is called “the Piaget effect” because it illustrates Piaget’s argument against unnatural efforts to speed up early development, such as training children to perform complex tasks in the way that circus trainers teach bears to ride bicycles (e.g., Piaget, 1936/1952, 1975/1985). Such perturbations in normal development can produce the unintended consequence of disturbing natural patterns of development. This model illustrates how dynamic modeling can reconcile what appear to be disparate aspects of growth (different trajectories for similar types of abilities) while also revealing unexpected outcomes (the Piaget effect) that stimulate empirical research. In short, the model shows how widely different patterns can emerge from the exact same underlying model of growth!

Importantly, the hierarchical growth model only characterizes one of several families of developmental shapes. Other models relevant to development include predator-prey models that specify the dynamic relationship between components that show support and competition
but no hierarchical integration (Thatcher, 1998). For example, cats and mice show a stable predator-prey relationship: The number of mice available at any one time will, in part, determine the number of cats that survive. If there are many mice, more cats will survive in a given season. However, too many cats in turn lead to fewer mice the following season, which in turn constrains the number of cats that survive in the next season. Research has found that similar predator-prey relationships exist for cognitive and neurological processes, such as the development of connections between cortical regions (Fischer & Rose, 1996).

Developmental processes are highly nonlinear, heterogeneous, and dependent on a wide range of factors. For this reason, dynamic models are well suited for the study of cognitive development, bringing together many interacting factors to specify patterns of development and learning rigorously and precisely. In short, dynamic modeling offers tools to better understand development and learning in their full complexity, integrating influences involving person, context, and culture.

CONCLUSION: STABILITY GROWS FROM THE DYNAMICS OF VARIATION

From grand theories of stable monolithic development to atomistic theories that focus on domain-specific change, neo-Piagetian work on development has created a balanced model in the form of dynamic structuralism. It is crystal clear that stability and variability are complementary hallmarks of development, not separate issues. Capturing the richness and complexity of development requires models capable of analyzing both of these simultaneously. Dynamic structuralism shifts the understanding of structure beyond static form toward dynamic organization, which depends not on prespecified innate representations but instead on continual real-time interactions between person, context, and culture. When development is viewed through the lens of dynamic structuralism, many classic controversies – such as whether stages exist – are revealed as artifacts of misconceptions. The organization of behavior clearly develops systematically, as Piaget described, and it also varies from moment to moment. These facts are only contrary for overly simple concepts of stage and variation.

We human beings construct knowledge through our own unique bodies and distinct sociocultural relationships, thus producing highly variable patterns of behavior. If this variability is ignored or marginalized, it serves only as noise to disguise the nature of developmental processes, and it will often mislead researchers and educators. However, if the full
range of methods, tools, and concepts are used to study the dynamic and complex properties of behavior, then patterns of variability can be revealed and illuminate the nature and development of knowledge and action.

REFERENCES


Spelke, E. S. (2005). Big answers from little people. *Scientific American*, 16(3), 38–43.


