1 Dialectical Constructivism: The Working Mind Underlying Working Memory

A brief description of the working mind, formulating epistemological notions relevant to model it organismically, is presented. We discuss the need to adopt in constructivist science a perspective "from within" the subject matter (or the subject). Causal mechanisms of organismic dynamics are introduced, among them resistances of reality to human action and the overdetermination process that synthesizes human action. Constructivist-learning (without mental attention) versus constructivist maturational-attention theories are discussed. We examine organismic-causal processes that explain emergence of working memory and task analyze the Raven Matrices Test to illustrate how constructivist causal processes can explain working memory and the emergence of fluid intelligence.

> One demonstrates the real, one cannot show it. … In fact, because the object appears as a complex of relations, one must capture it by multiple methods.
>
> —Bachelard, 1934/1987, p. 16, translated by JPL

> There is indeed a problem: On which factors depend initial disequilibrations? This was a new problem for us because heretofore we had mistakenly considered initial disequilibrations as not needing explanation or resulting from difficulties of synthesis.
>
> —Piaget, 1974, p. 155, translated by JPL

> For Hegel … the power of the spirit lies in synthesis as the mediation of all contradictions.
>
> —Gadamer, 1971, p. 105

The *working mind* is the active unconscious or conscious processes (affective and cognitive) that synthesize meaningful experiences and produce problem solving and learning. These processes involve mental attention directed to the person's own thoughts, whether addressed to the external situation or internal states. They also involve associative knowledge and perceptual attention driven by expectancies, which stem from inferentially constructed knowledge schemes. This working mind is the product of a *working brain* (Luria, 1973). To model a working mind, one must adopt a perspective from within the subject's processes. Such description should include internal and external processes, interpreting external situations and tasks in terms of the mind/brain working processes involved. Explicitly functional neuropsychological theorizing (modeled from within the subject's mind) is necessary. This sort of macro theorizing can be interpreted within the working brain as neural circuits and brain regulations, as we attempt to do in chapters 10 and 11.

The preface provides an overview of the theory. As mentioned there, we use the term *metasubjective* for our approach to modeling processes *from within* (Pascual-Leone, 2013; Pascual-Leone, Pascual-Leone, & Arsalidou, 2015; Pascual-Leone & Johnson, 2017). This approach aims to capture in explicit process models the evolving *functional totality* of a subject's inner processes. Here, *totality* stands for all intercoordinated processes that in the subject produce and control behavior. We call it *functional*, because this totality of processes is psychologically described by the structure of the process's own functioning. Our approach contrasts with often-adopted modeling from an *observer's perspective*, "from outside" the subject.

The Copernican Revolution can be used to illustrate the constructivist or metasubjective versus the observer's meta-empiricist approaches collaborating to advance knowledge in science (Pascual-Leone, 2012b, 2013; Pascual-Leone & Johnson, 2017). Our interpretation of Feyerabend (1978) suggests that the insight that brought Copernicus to his heliocentric viewpoint was a metasubjective turn (i.e., toward dialectical constructivist thinking). Ptolemy's intuitions about movement of the sun and stars were more congruent with the everyday experience of people who look at the sky and watch the sun and moon move about with them. Copernicus, however, rejected the observer's perspective and placed himself intuitively within the cosmos itself: he experienced the dynamic object-interaction and activity of this cosmos from within it. He anticipated rationally, against sensorial appearances, that taking the sun as rotation axis in our planetary system is a more congruent solution for this dynamic functional totality—a simpler solution for the empirically found repeatable (inter-) relations (Ullmo, 1967). At the time the Ptolemaic system could indeed make more precise, albeit empiricist, predictions than Copernicus's own (Feyerabend, 1978). Copernicus's metasubjective turn promoted a new *constructivist* form of empirical research from within the cosmos itself (not just an external observer's analysis as in Ptolemy). This new way of making science provides a causal process account: placing emphasis on internal constraints and external resistances of nature as a functional totality, not on the local empirical appearances (Bachelard, 1981).

Similarly, in metasubjective psychology what are relevant are the internal constraints that the organism brings to a task, as well as the reality resistances opposed to the organism and its activities. *Resistances* are obstacles to goal-directed action, caused by situations[1] or our organism. Metasubjective theories help to clarify such resistances. Talking about science, Bachelard (1980) said, "The first specific instance of the notion of matter is the *resistance*" (p. 10; translated by JPL). Metasubjective analysis can help us to model the internal constraints and resistances of the organism, as a dynamic totality within the task.

This book offers, in the form of a scientific essay, a metasubjective general theory/model of neuropsychological processes. This theory is dialectical-constructivist in its epistemology and neo-Piagetian in its origin. The focus of the theory is developmental: explaining how and why the working mind's ability to cope with truly novel situations (often called *problem solving*) increases with age, demarcating stages. It does so by using constructs (schemes and organismic regulations—hidden constructive operators) that are constant functional manifestations of the working brain. We consider the theory to be organismic and constructivist-causal.

The term *organismic* (Pascual-Leone, 1984) was introduced by Goldstein (1934/2000; Werner & Kaplan, 1984), who spoke of "equalization" processes (in the sense of Piaget's later "equilibration") of the "organism as a whole." *Organismic* here refers to the organism as a very active, organized functional totality with its own essential nature, which is purposeful and dialectically driven toward maintaining balance/equilibration of the working mind (Pascual-Leone, 2014). Working-mind processes are rooted in the brain and can be modeled from within as discrete macroprocesses that codetermine task performances. Such modeling is *metasubjective analysis* (Arsalidou, Pascual-Leone, & Johnson, 2010; Pascual-Leone, 1995, 2013; Pascual-Leone et al., 2015).

A theory or model is *descriptive* when it offers ways to express encountered phenomena and structural findings. In contrast, a model is *causal* when its constructs are distinct from descriptive constructs to be explained and can be independently anchored on experience via experimentation. These causal constructs account for change that descriptive constructs (data) undergo with experience, maturation, and organismic transformations. Note that by "causal" we mean organismic causal overdetermination, as discussed below. Descriptive and causal theories or models can be *local* versus *general* (Pascual-Leone, 1978). These distinct sorts of theories/models are all jointly needed. Combined, they yield two dimensions of variation (i.e., local vs. general and descriptive vs. causal) that can be crossed. Thus, simplifying, there are local descriptive, general descriptive, local causal (Pepper's, 1942, "mechanistic"), and general causal

(Pepper's "organismic") theories or models. This is important because the more general a causal theory is, the more distinctly differentiated it will be from the descriptive structural theories it aims to explain and coordinate. The more local, the less differentiated causal theories will tend to be from their descriptive theories, eventually leading the distinction to collapse (Pascual-Leone & Johnson, 2005). Note that a causal theory/model (unlike purely descriptive ones) must have an explicit sequential account of how change-as-process occurs: showing how consequent conditions emerge via causal overdetermination from context and antecedent organismic conditions. So defined, organismic-causal general models are much needed but rare in cognitive development or in psychometrics (Gottfredson, 2016).

It is important for a causal theory to address problem solving. From an organismic-causal perspective, problem-solving processes are those that dynamically synthesize *truly novel* (external or mental) *performances*. These are novel performances that are not directly learned nor maturationally acquired, nor are they automatic results of learned coordination. They result instead from "creative" *dynamic syntheses*, often generating truly novel complex schemes that can help to solve intended problems and remain in the person's repertoire (long-term memory) as potential components of future solution alternatives (see Shipstead, Lindsey, Marshall, & Engle, 2014). As Gestalt psychologists (Koffka, 1935/1963) and others have assumed, dynamic syntheses in misleading situations (typical of problem solving) result from various *organismic resource factors* (general-purpose brain operators) whose interactions cause representational and operative syntheses, making intelligence, the symbolic function, and learning possible. Our theory has four distinct characteristics: it is founded epistemologically in dialectical constructivism; it is metasubjective; it yields a powerful, truly novel method of metasubjective task analysis; and its constructs are interpretable in the working brain.

Why Dialectical Constructivism?

A theory of development and learning is *constructivist* when it minimizes (albeit recognizing) both content-bound maturational predeterminations and passive empiricist (i.e., simple associative) learning, emphasizing instead the learning/internalization from experience of *functional invariants* (i.e., recurrent functional patterns) that express or embody Resistances that Reality presents to the person's agency or praxis (a view pioneered by Cassirer, 1923/1953, 1938, 1929/1957; Gonseth, 1936/1974; Ullmo, 1967). Such a theory creates suitable, situated internal models that emphasize innate biogenetic determinants enabling adaptation via constructivist learning. These models serve as dynamic functional structures for *agency* or *praxis* (i.e., conscious or unconscious goal-directed activity addressed to the environment), structures that cope with types of situations. Cassirer called them symbolic forms (Cassirer, 1929/1957, 1944/1966), and Piaget either *schemes* or *functional structures/schemas* (more recently called chunks by empiricists)—all of them stable or invariant coordinations of schemes. These internal models are the result of neural plasticity, which internalizes suitably adapted, relevant, probabilistically invariant patterns of coping with experience, thus increasing life adaptation and survival.

The organism encounters anomalies in its (implicit or explicit) expectations about reality. Such anomalies occur whenever situations offer unexpected Resistances to the subject's agency/praxis (*Resistances* in capitals, to signify Reality as such). Piaget and others called these Resistances *perturbations*. Perturbations elicit in the organism an endogenous process of functional arousal, with evaluations and change (often unconscious) toward re-equilibration. This is part of what Piaget called *optimizing equilibration* (successful adaptive rebalancing of the working mind).

As both Piaget and Tolman emphasized, meaning-bearing processes in the organism (i.e., Piaget's schemes and structures/schemas) carry within them *expectancies* about what should happen next, conditional to what has happened before. In developmental constructivism the meaning-bearing processes are unitized into schemes/schemas that carry local expectancies about what leads to what in the current situation. They are packaged into unitized schemes, that is, functional dynamic totalities, local mini-systems. Because schemes are distinct and relatively segregated, they are able to functionally differentiate between distinct and segregated Resistances of the situation, thus allowing emergence of selective adaptive expectancies. This is so whether these expectancies bear on external reality or on results from one's actions (examples are Tolman's [1959, 1961] means-end expectancies and Piaget's operations).

When expectancies are violated by experience (errors of anticipation), a loss of organismic dynamic balance occurs. Piaget (1975/1985) called it *disequilibration*. It produces organismic arousal that mobilizes both automatic-perceptual and mental attention to (perhaps automatically) explore and search for concrete differences between the new situation (in which violation of expectancy has happened) and other "normal" situations that conform to the expectancy. This is the organism's initial attempt to resolve anomalies and restore equilibrium. Such an organism is constructivist: it seeks to increase adaptation by reworking or reorganizing meaning-bearing (cognitive or affective) inner processes (schemes) to resolve anomalies, eliminate resistances, and simplify processing.

Notice the epistemological affinities of this developmental constructivism with current dynamic field theories, dynamic system theories, or computational rationality

(Gershman, Horvitz, & Tenenbaum, 2015; Schöner, 2014; Spencer, Perone, & Buss, 2011). They are all dynamic process theories that produce performances by synthesizing in situ multiple distinct processes (in our case, schemes) that, in their coordination, make the (internal or external) performance emerge. The big difference of developmental/dialectical constructivism, as we present it in this book, is the qualitative-process schemes or schemas (described above and in chapter 5), together with explicit organismic hidden operators and principles that provide a causal account for dynamic descriptive formulations offered by other field or system probabilistic-process approaches.

Piaget's constructivism was a biologically grounded *empirical rationalism*, which envisioned human organisms as seeking to adapt by developing internal intelligent models that cause re-equilibrations, which in turn expand the scope of situations in which the organism can be well adapted (Pascual-Leone, Escobar, & Johnson, 2012). For clarity, we should distinguish two kinds of constructivism. The first, *categorical constructivism*, is clearly found in Piaget's early writings (up to the late 1960s), as it is found in Kant's and (often tacitly) in that of many current cognitive scientists. This is a constructivism in which higher-order organizing principles or categories are posited top-down by dictum and used as organizers without sufficient developmental, learning, or evolutionary justification. In Kant (1929/1965) the transcendental intuitions of space and time and transcendental categories such as quality, relation, substance, quantity, causality, and so forth arguably play this role, making experience possible.

In Piaget's writings there are stage-defining descriptive *psycho-logic models* meant to express metasubjective operative processes. They are inferred from functional-relational patterns in data across subjects, whose temporal change Piaget characterized into developmental stages: sensorimotor, preoperational, concrete operational, and formal operational. These models were formulated in interaction with dynamic/causal functional-system categories, such as schemes/structures, assimilation versus accommodation, physical/empirical abstractions versus reflective abstractions, equilibration, disturbances, and so on. Nonetheless these dynamic/causal categories are not well coordinated with Piaget's descriptive psycho-logical stage models. His causal process for stage changes is not formulated explicitly, leaving the theory causally inadequate. A more explicit *dialectical constructivism* is needed. This is the second kind of constructivism.

Dialectics (Mihalits & Valsiner, 2020; Pascual-Leone, 2014) is a mode of reasoning that emphasizes change within, and interactions among, process constituents (dynamic constructs) to bring about balance or coordination. This form of thinking may help to explain conflicts and competition among constituents and therefore the emergence of truly novel outcomes. To clarify dialectical constructivist epistemology, we critically analyze Piaget's approach. We do so because these criticisms also apply to many empiricist cognitive theories. Note that constructivist theories are empirical although not empiricist.

The later Piaget[2] explicitly became a dialectical constructivist (Inhelder, Garcia, & Voneche, 1977; Piaget, 1980, 1985) and made some attempt to coordinate his psychological models with dynamic process constructs; however, he never achieved a detailed integration (e.g., Inhelder et al., 1977; Piaget, 1974, 1975/1985; Piaget & Garcia, 1987). This problem is illustrated by his failure to formulate explicit and separate causal mechanisms to account for conflict (dialectical contradictions and negations) and explain equilibration processes (e.g., the third epigraph). Such omissions are fundamental, because negations/conflicts, re-equilibrations, and disequilibrations express central causal mechanisms in Piaget's and other dynamic theories (Inhelder et al., 1977; Piaget, 1974, 1975/1985). Indeed, as Piaget explicitly stated (in Inhelder et al., 1977), "What the notion of equilibration adds is, in contrast, the causal dimension; it is the work of the subject himself … to speak of progressive equilibration is to give the causal process (psychologically formulated) that generates structures, constructing them step by step" (p. 114, translation by JPL).

Sixteen lines later he added: "Thus what is causal in the theory of equilibration is the attempt, whether succeeded or failed, to explain what mathematicians *do* and not the nature of logico-mathematical structures" (p. 114, translation by JPL). However, attempts to explain *how* children (or mathematicians!) come to solve Piagetian tasks were not successful within Piagetian theory, as his collaborators and others have recognized (Inhelder et al., 1977; Valsiner, 2006). In his later work Piaget (1980) seriously sought a dynamic/dialectical reformulation of his theory, stating that "dialectics constitutes the inferential mechanism of equilibration" (p. 223, translation by JPL).

To understand dynamic theories of metasubjective change, including Piagetian theory, we should functionally explain dialectics and dialectical systems. Dialectics (a qualitative precursor of dynamic-systems analysis) studies competition among processes. Dialectics means the dynamic interaction that occurs between two or more sources (or distinct causal factors/determinants) of process, which often are in competition or mutual contradiction, even though they may functionally complement one another to codetermine outcomes. Leonardo da Vinci, in his analysis of the architectural arch, provides us with an example illustrating essential characteristics of dialectical systems. Reflecting on this milestone of architectural ingenuity, used since Roman times, da Vinci said, "What is an arch? An arch is nothing else than a strength caused by two weaknesses … as one withstands the downfall of the other the two weaknesses are converted into a single strength" (da Vinci, 1959, p. 210).

Each segment of an arch, due to gravity, thus exemplifies a dynamic constituent of this functional totality whose normal output is to fall. However, the two segments oppose each other (are in contradiction), and each in fact regulates or adaptively modifies the effect of the other. Together they cause a new outcome or invariant, the cancellation of the effects of gravity resulting in stability of the arch. Thus described, an arch illustrates a minimal dialectical system constituted by two subsystems, the arch segments, in dynamic interaction. We will say that two or more dynamic systems constitute an overall functional totality or *dialectical system* (**DS**) whenever:

(**DS1**) each (sub) system is *contradictory* with the others in its functional effects

(**DS2**) effects of each of them *regulate*, compensate, or adaptively modify effects of the others

(**DS3**) all of them are jointly needed to generate an *emergent* functional *invariant*, which often is a truly novel performance

Contradictory means that the two terms have effects vis-à-vis the total system that lead to different dynamic outcomes, which may at least in part cancel one another. For instance, each segment of an arch falls literally against the other segment. *Regulate* means that each of the subsystems can in fact influence the dynamic consequences of the other(s), setting dynamic limits to its/their manifestations; the falling of each arch segment is curtailed by the falling of the other segment. *Emergent* is a property or entity that suddenly appears: that is, a truly novel happening that marks the existence of a replicable *invariant,* probabilistically invariant because it reoccurs as a truly novel event (performance pattern) whenever opposing dialectical subsystems interact in appropriate circumstances. Notice that dialectics also involves a focus on processes and on the changing nature of experience and reality (as dynamic field/system theories currently do). As Lenin writes, quoting Engels: "Dialectics is the science of the general laws of motion, both of the external world and of human thought" (Marx, Engels, & Lenin, 1977, p. 374).

An example of dialectical emergence in cognitive development is babies learning to walk (W). By about 12 months a baby has learned, by trial and error, to stand on her feet unaided. The product of this intentional learning is a scheme system for *free standing* (call this skill W1). Then, because she wants to walk unaided, she learns to unbalance herself from this position, by raising one leg and hip and immediately letting herself fall momentarily on this leg in a controlled manner (call this skill W2). As it falls, the leg becomes firm to allow the child to land on it. Let us call *controlled falling* the operative scheme system of W2. At this moment, the baby is *standing* on one leg

(W3), and she unbalances herself on the other leg and hip (W2′, similar to W2). Then she makes firm this moving leg to enable her landing on it (W3′, similar to W3). This walking sequence recurs: W1-W2-W3-W2′-W3′-W2-W3-W2′-W3′…

After some persistence in practice, the child can walk by herself if, and only if, she has enough sensorimotor maturational attention to boost together all the relevant schemes in order to produce a suitable dynamic synthesis. The infancy literature usually assumes that no working mind is needed, because the walking scheme is innate. Some conditions or parameters necessary for walking indeed are innate, but not the walking skill itself. This process analysis shows that walking is synthesized by the 12-month-old infant's mind: synthesized as a controlled form of regulated falling, regulated by the alternation of the scheme *falling* (i.e., W2 and W2′) with the scheme *standing* (W3 and W3′). These two contradictory scheme systems (like the two arms of da Vinci's arch) regulate each other with their controlled alternation, permitting dynamic emergence of this truly novel repeatable outcome (new performance invariant), the skill of walking.

Emergence of functional invariants generated by dialectical/dynamic systems enables humans and other animals, during development or learning (with brain maturation or neuroplasticity), to achieve truly new characteristic, behavioral or mental, performances of all sorts. These performances are not innate nor, strictly speaking, learned, but dynamically synthesized. Thus, different truly novel perceptual-motor or mental acts appear, again and again, under suitable circumstances.

Dialectical systems are continuously acquired, dynamically synthesized, throughout development. Age-typical performances characteristic of developmental stages provide examples, but there are many others: creativity, problem-solving strategies, self-acquired techniques, human social interactions, life adaptations, and so on. When one looks closely, most innovations result from dialectical/dynamic syntheses that often are serendipitous.

In his later work Piaget studied this sort of constructivist dialectics using two functional categories first introduced by Hegel (the founder of modern dialectics): affirmations and negations, two complementary forms of performance process (Inhelder et al., 1977; Piaget, 1974, 1975/1985). *Affirmations* are processes (of any level of complexity) that are more or less congruent with the intended current cognitive-structural processing (by stage-related developmental schemes/structures) and congruent with the intended agency/praxis. *Negations* are often *distracting processes*, incongruent or dialectically contradictory with the current affirmations, or they are *misleading processes* that induce performances that lower probability of the intended praxis. However, in a positive sense, negations can also be inverse operations in a well-equilibrated operational system, or even "perturbations" that favor development by disequilibrating inadequate schemes or structures of the cognitive state (e.g., in Piaget's terms, when a preoperational structure is negated by newly experienced contradictory and perturbing feedback).

Piaget used affirmations and negations categorically, without making sufficiently clear that they are relative to the praxis at hand. Nonetheless, he raised an important point: to enhance performance by differentiation of responses, one must regulate (i.e., compensate by means of suitable affirmations or negations) all negation or affirmation processes that may emerge. For instance, the person who in ancient Rome invented the architectural arch discovered how to place the two arms in perfect opposition, each of them compensating the other (as regulated negation/affirmation). Only then could a truly new object, the stable arch, emerge. This case also illustrates, by using a minimal number of dialectical opposites, Piaget's claim that in *well-equilibrated* systems each affirmation is compensated or balanced by its own negation, and vice versa (Piaget, 1974, 1975/1985). As Piaget emphasized, affirmations tend to be observed and appear first developmentally, because negations (or inverse operations) are harder to notice (i.e., less salient, less facilitated) in ordinary situations. However, Piaget seemed unaware that negations are typically more salient than affirmations within misleading situations, as we shall illustrate. In either case, until a mutual compensation between affirmations and negations occurs, a truly equilibrated (e.g., a Piagetian operational) system is not possible (Piaget, 1975/1985).

In psychological processes, affirmations are schemes (or organismic dispositions) relevant for the intended praxis. Negations are generally either external features of the situation that are inconvenient and must be overcome, or internal schemes (habits, automatized schemes, or organismic tendencies) that are misleading, because they propitiate unwanted performances. In either case, success depends on applying affirmative schemes that can dynamically compensate and neutralize unwanted negations. For instance, in the well-known Stroop task (naming the ink color of words that name other irrelevant colors), the affirmations are name schemes for the actual ink color; the negations are (color) schemes being cued by the word names, which tend to be more salient when reading is automatized. In the Piagetian conservation of substance task that uses Plasticine, negations are either representations of external features suggesting greater amount (e.g., a long sausage) or internal schemes (e.g., a tendency learned in everyday life and facilitated by the field factor, the neo-Gestaltist simplicity principle, is to equate a larger perceptual appearance with a bigger object). As Piaget's descriptive (not causal) analyses imply, success in misleading situations, in which dialectical negations must be controlled, depends on the ability to neutralize all misleading factors with the help of suitably chosen affirmative schemes, which the persons either have in their repertoire or can synthesize dynamically.

Causal Mechanisms for Organismic Dynamics

Piaget and his collaborators (Garcia, 1980; Inhelder et al., 1977; Pascual-Leone, 1987; Piaget, 1975/1985) recognized a main objection to their dynamic theory: It gives "description and provides no explanation" (Piaget, 1975/1985, p. 147). It offers "optimizing/progressive equilibration" as a causal organismic process to explain truly novel performances and stages of cognitive development but gives no coherent analytical account of the organismic factors that may cause equilibrations. Piaget's equilibration construct is the name for a problem. Indeed, this *optimizing/progressive equilibration* (**OE**) involves three subprinciples that Piaget failed to distinguish (Pascual-Leone & Goodman, 1979), although they metatheoretically express well the synthetic disposition of the working mind. It is an active (self-propelling, endogenous) disposition of the organism to undergo restructuration (i.e., structural change) spontaneously via dynamic syntheses, in order to:

(**OE1**) maximize the internal consistency among its functional parts

(**OE2**) maximize the scope of adaptation (its functional payoff) in dealing with the environment: that is, maximize the number of different types of situations to which the organism can adapt without having to learn (i.e., change its internal structures)

(**OE3**) minimize internal complexity (structural cost) in its organization

These three subprinciples should lead to extraction of new invariants across variable functional aspects in the situations.

To explain analytically how the working mind could satisfy these three subprinciples in a constructivist manner, we must assume the existence of multiple, qualitatively different general-purpose brain resources, or *hidden operators,* that could generate multiple learning mechanisms. Because the organism is very active and self-propelling, its functional schemes and structures (i.e., complex schemes) serve as self-organizing dynamic systems driven by *assimilation* (self-propelling disposition to apply). Schemes also *accommodate* (adapt) when they must, when Resistances from Reality cannot be avoided and cause intolerable anomalies. In chapters 10 and 11 we discuss neuroscientific evidence suggesting that the assimilation and accommodation functions may be expressed in distinct complementary pathways of the cortex. A neglected implication of this sort of theorizing is that any performance typically should be *overdetermined* by all schemes that could apply due to the assimilation tendency. Thus, performances often should result from *dynamic syntheses* (as dialectical thinkers often have claimed; e.g., Gadamer, 1971; Kant, 1929/1965; Luria, 1973; Marx et al., 1977; Vygotsky, 1978; Vygotsky & Luria, 1994). Such syntheses, combining task-applicable schemes that can epistemically reflect Reality, may be related to processes that Peirce called abduction (Buchler, 1955; Johansen, 1993).

For Piaget, dynamic syntheses are carried out by what he called *regulations*—a notion he left unexplicated (Garcia, 1980; Inhelder et al., 1977; Pascual-Leone, 1969, 1970, 1987, 1988; Pascual-Leone & Johnson, 2005; Piaget, 1967, 1975/1985). Regulations cause optimizing equilibration when different dialectical factors are involved and some organismic resources (cause of regulations) intervene, which brings about adaptive syntheses. These resources (for us brain capacities or *operators*) should be information free, general purpose, distinct, and independent from schemes. Such general-purpose capacities (hidden operators and principles in this book) were ignored by Piaget as they often are by current researchers.

Consider again briefly dialectical processes. Luria (1973), Piaget (1980, 1975/1985), Vygotsky (Kozulin, 1990), and others agree with this idea: there are three complementary types of (complex) dialectics, which together promote individual adaptation and development: (1) *purely external dialectics* between the individual and his or her life context; (2) *external intersubjective dialectics,* from each person to other persons, often psychosocial and sociocultural; and (3) *purely internal dialectics* interrelating psychological processing components (cognitive, affective, and personal schemes, with general-purpose brain capacities) within the individual. These three distinct sorts of dialectics lead to complex interactive situations that should be experienced subjectively as well as objectively.

In this respect, we must emphasize the difference between *facilitating* and *misleading situations* (Arsalidou et al., 2010; Pascual-Leone, 1987; Pascual-Leone & Johnson, 2005, 2017; Pascual-Leone & Morra, 1991). This important distinction is not found in Piaget or Vygotsky and often is ignored in current cognitive science and neuroscience. Metasubjectively, a situation is facilitating when it activates only schemes compatible with the task at hand. It is misleading when it elicits schemes that interfere with the task.

Facilitating situations elicit schemes that contribute to (or do not interfere with) the person's task. Such situations traditionally have been used by learning researchers. Development appears continuous when studied using facilitating situations, a linear growth function being its characteristic curve. Misleading situations, in contrast, are typical of problem-solving paradigms. Such situations reveal coping, problem-solving levels in cognitive development. Development appears as discontinuous in misleading situations, exhibiting (at times stepwise) nonlinear growth curves in tasks as a function of chronological age (Arsalidou et al., 2010; Johnson, Fabian, & Pascual-Leone, 1989; Pascual-Leone, 1970; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2005, 2011; Pascual-Leone & Morra, 1991). Note that this is found more easily in cross-sectional studies, where learning, due to repeated testing (as found in longitudinal studies), does not occur. However, longitudinal studies are necessary to validate cross-sectional results.

Thus, stages of development are found reliably (as relatively culture-fair, age-bound differences) only in chosen misleading situations. In these misleading paradigms, performance tends to conform to what descriptive, nonlinear system theories, like catastrophe theory (Camba, 2014; Molenaar & van der Maas, 1994; van der Maas, 1993) would predict. This has led to claims that development should be explained with nonlinear system theories (e.g., Thelen & Smith, 1994), although the organismic causal factors that produce these "catastrophes" in performance are never clearly investigated.

Stages of development appear in misleading situations because mental attention is needed by the working mind to inhibit and control unsuitable habits (due to overlearned schemes or innate reflexes), cued by situations and by organismic factors that make them salient. These misleading schemes induce competing mistaken strategies, or interfering processes (dialectical contradictions, negations), relative to intended/desirable action or results. Individuals must use problem solving in misleading situations—nonautomatized methods (e.g., invention and creative, synthesized truly novel performances) to cope with demands. Dynamic syntheses that generate the task solution are caused by compatible dominant schemes applying together to overdetermine performance.

Performance and the mind's mentation are always overdetermined by all schemes or schemas activated by the situation and boosted or controlled by active hidden operators of the brain. These dynamic syntheses are achieved automatically by the principle of *Schemes' Overdetermination of Performance* (*SOP*). This *SOP* principle was first formulated by Freud (Rapaport, 1960) and used in human science by sociologists (Callari & Ruccio, 1996) among others. It postulates that performance and mentation always result from unifying adaptive integrations (*SOP*) of the activated processes (this is a position also taken by current dynamic field theories, e.g., Schöner, 2014, although less explicitly than dialectical constructivism). Schemes/schemas, hidden operators, and organismic principles competitively coadapt to "negotiate" the resulting performance or mentation.

To clarify this important *SOP* dialectics, consider an invented "Freudian" example of how *SOP* works: A high-ranking executive is discussing business in the office with an attractive female subordinate executive. As he excitedly argues some business points, he comes closer to her and in his mind notices her lovely face and attractive attire. He is mindfully aware that he should not express his attraction to her, and he continues calmly arguing the business points. However, unconsciously, he stretches his right hand to lean on the wall she is standing near. His arm is now in front of her, as a friendly barrier. She does not react; he is at a reasonable distance. They continue their conversation, holding the mutual posture, with his arm-and-wall now looping around her in a symbolic (perhaps unconscious) "proper" embrace.

Note that his posture emerged from the synthesis of several contradictory schemes (**sch**): (**sch1**) desire, perhaps suppressed from consciousness; (**sch2**) a wish to embrace her, perhaps unconscious; (**sch3**) some ethical schemes of proper conduct related to women colleagues; (**sch4**) interest in the conversation leading him to move closer to her; (**sch5**) some unconscious desire to ease his tired feet, and so on. The "Freudian" interpretation, which the *SOP* principle and our Theory of Constructive Operators (TCO) in fact predict, is that **sch1**, compelling although perhaps unconscious, elicits activation in his working mind of **sch2**, which in turn elicits activation of **sch3**. This personal (affective *and* cognitive, emotional) conflict unconsciously promotes (via *SOP*) a new bodily posture that also is congruent with, and induced by, **sch4** and **sch5**. This is the posture of leaning on the wall: symbolically (but without moral transgression) he is now embracing her (at a distance) with the help of the wall. The example illustrates how *SOP* helps to solve conflict situations (with any sort of schemes, affective or not) by symbolically working out compromises among competing or compatible activated schemes. This is a new way of looking at psychological and brain processes as products of two sorts of operators, schemes (subjective operators) and hidden operators, which codetermine processes in the working mind by automatically producing dynamic syntheses among affirmative and negative schemes.

Overdetermination is a multidetermination in which causal factors interact in nonlinear ways, within the organism and the working mind. It explains dynamic/dialectical syntheses in a manner consistent with neuroscience. (For example, the brain's cortical spreading of activation among connected neurons, regulated by lateral inhibition, is an overdetermination process.) Overdetermination can also be seen as expressing Piaget's assimilation function, which compels schemes to apply together when compatible, or as a generalization of Sherrington's neural principle of a final common path (neuronal spreading of activation and its convergence; Edelman, 1987; Edelman & Tononi, 2000; McFarland & Sibly, 1975; Sherrington, 1906). According to this principle, all schemes active within a situation tend to apply together, if compatible, to codetermine performance. Sherrington seems to have shared this generalized principle of convergence: "Where it is a question of 'mind' the nervous system does not integrate itself by centralization upon one pontifical cell. Rather it elaborates a million-fold democracy whose each unit is a cell" (1940, p. 277). Thus, performance at every moment is synthesized by the currently *dominant* (most activated) *cluster of compatible schemes/processes*. These schemes often compete with interfering schemes. The probability of this performance is proportional to the relative dominance of the current cluster of compatible schemes generating it, relative to other clusters.

Dynamic syntheses result from application of hidden operators and organismic principles (Pascual-Leone & Goodman, 1979), often coordinated by executive processes. Piaget's theory lacked these organismic causal constructs (e.g., executive processes, mental attention, attentional inhibition/interruption, *SOP*; Morra, Gobbo, Marini, & Sheese, 2008; Pascual-Leone, 1987, 1996b; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2005, 2017). Resolution of this scheme competition obeys three optimizing-equilibration rules (**OE1**, **OE2**, and **OE3**) mentioned above. Rules **OE1** and **OE2** (i.e., maximize internal consistency and maximize scope of adaptation) result from an overdetermination of performance (*SOP*) by action schemes regulated with executive schemes, which set the course (cognitive goals) and direction (in action or thought) to serve current intentions (affective goals or motives). These **OE1** and **OE2** equilibration processes are biased by dialectical intertwining between cognitive and affective processes, the origin of complex motivation. Piaget and many current cognitive scientists lack clear models interfacing cognition with affects (affective schemes) to generate complex motivation (affective goals or motives).

Regarding **OE3** (i.e., minimize internal complexity in the organism), another factor, only informally used and mentioned by Piaget and others, is important. This is the brain resource that Gestalt psychologists (Koffka, 1935/1963) and Piaget called (internal) *field factor* and we call *F*-operator (Pascual-Leone, 1989; Pascual-Leone & Morra, 1991). A neuroscientific interpretation of this factor is lateral inhibition processes in the cortex (e.g., Edelman, 1987; see chapter 10). Psychologically, this factor expresses a performance-closure mechanism akin to the neo-Gestaltist principles of "Pragnanz," "minimum," "simplicity/simplexity," and "S-R compatibility" (Berthoz, 2012; Pascual-Leone & Morra, 1991; Proctor & Reeve, 1990; Rock, 1983).

This organismic *F*-factor, in interaction with *SOP*, produces a sort of *minimax-function* effect that we formulate as follows: The performance produced will tend to be such that it minimizes the number of schemes directly applying to inform performance (including perception or representation), and it does so while maximizing the set of distinct, salient empirical aspects or features (i.e., applied low-level schemes) that, directly or indirectly, inform this experience (Pascual-Leone, 1987, 1995, 1996b; Pascual-Leone & Johnson, 1991, 2005; Pascual-Leone & Morra, 1991).

For example, errors in the picture completion subtest of the Weschler Intelligence Scale, such as failing to see the missing doorknob in the picture of a door, are caused by this *F* minimax mechanism. This *F*-factor prevents application of low-level (local-perceptual) schemes, like the simple doorknob scheme, when higher-order automatized schemes, like the structure of a standard door with its own doorknob, can also be applied: *F* suppresses, via lateral inhibition (see chapter 10), the application of the simpler lower-level doorknob scheme.

Aspect **OE3** of optimizing equilibration can be explained by *F* in conjunction with *SOP*, together with the need to minimize processing. Optimizing equilibration, and other organismic resolution-syntheses of performance, can be explained by assuming brain capacities and principles other than schemes that Piaget's theory clearly lacks, as do most current learning theories. Our theory (the TCO) is not simply an elaboration of Piaget's theory, because Piaget's theory is a *developmental cognitive-learning theory*. For him, development occurs because learning accumulates and (aided by unexplicated maturation) causes development. Piaget (possibly contrary to Binet and Spearman) did not believe that there is another factor such as mental "energy" or endogenous attention that is subject to maturation and can function as specific organismic cause of psychological-developmental stages. When one of us (Juan Pascual-Leone) personally told Piaget that mental attention, or "mental energy," grows with his stages, he was in disbelief. Piaget refused to entertain this hypothesis and told JPL that he would never be able to prove this idea. But we have proved it, and the TCO is a result. Since most psychologists are also cognitive-learning developmental theorists (and not mental-attention developmental theorists), stressing the theoretical difference with Piaget is necessary, even though the TCO explicates Piaget's theory very well.

Piaget did not explicate the maturation concept, nor had he other general-purpose innate "central" constructs like *F*, or maturational mental attention (which we call *M*-operator), or maturational attentional inhibition/interruption (which we call *I*-operator). Current cognitive-science researchers often resemble Piaget in their lack of enough organismic-causal (working-mind) operators to explain performance and developmental growth.

Two Types of Constructivist Developmental (Neo-Piagetian) Theories

Neo-Piagetian theories explain cognitive growth as caused by incrementation in the processing of *effective complexity*, due to acquisition of schemes/schemas that generate performance, facilitated by increase in mental attention, working memory, and other resources. Developmental constructivists have different views on what causes transitions from one stage to the next. Some neo-Piagetians, and most adult working-memory researchers, support what we might call the *constructivist learning* group of theories. They see developmental growth as caused by some form of insightful (since the role of consciousness often is assumed) constructivist learning. Piaget is part of this group and would have equated constructivist learning with psychogenetic/developmental intelligence. For Piaget, developmental intelligence had four distinct main causal factors: *maturation* (innate organismic determinants), *specific learning* (cognitive, affective, and motivational modes related to tasks and particular situations, across domains), *general/social learning* (affective, psychosocial, cultural, historical modes and knowledge—across domains), and *equilibration* (organismic internal balance; developmental, problem-solving, and learning adaptation). Demetriou and colleagues (Demetriou & Spanoudis, 2018; Demetriou, Spanoudis, & Shayer, 2014; Spanoudis, Demetriou, Kazi, Giorgala, & Zenonos, 2015) call *cognizance* a related encompassing construct for which, unlike Piaget, they seem to consider consciousness the primary causal factor (as do some other cognitive scientists, e.g., Dehaene, 2014).

Constructivist learning often is seen as producing durable internalization of recurrent functional patterns of processing and behavior, achieved by way of complex schemes (schemas, functional structures, chunks) at various complexity levels and in different content domains. Constructivist learning theorists interpret the growth in working memory or mental attention (which Piaget called "field of centration" or "field of equilibrium") as a product of cognitive learning. Demetriou's current theory (Demetriou & Spanoudis, 2018; Demetriou et al., 2014; Pascual-Leone, 2019; Spanoudis et al., 2015) may be the version of constructivist learning theories that has been more thoroughly investigated psychometrically. This and other neo-Piagetian theories are discussed by Arsalidou and Pascual-Leone (2016), and we refer readers to this source.

Other neo-Piagetians, who constitute the *maturational-attention group* of theories, agree with the importance of constructivist learning but think that this sort of learning (in contrast to associative learning) is possible only with the maturational growth of a limited resource: that is, mental/executive attention, often misnamed as working memory (e.g., Case, 1998; Halford, Cowan, & Andrews, 2007; Halford, Wilson, Andrews, & Phillips, 2014; Morra & Borella, 2015; Pascual-Leone, 1970; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2005, 2011; Pascual-Leone, Johnson, & Agostino, 2010; Petersen & Posner, 2012). Maturational attention is a key determinant of working memory, but this is not the only determinant. Working memory, as it is commonly understood, demands other organismic-causal factors, perhaps all the factors important for a working mind. This maturational attention group of theories has shown that mental-attentional mechanisms grow in power as a function of age in normal children; this growth (along with other causes) relates to emergence of developmental stages.

For Robbie Case cognitive abilities improve within substages due to the qualitative gain in proficiency of *central conceptual structures* (mental-operational complex schemes) caused by constructivist learning and mental attention. Case (and many others) confused mental attention with working memory, even though he used learning constructs of Pascual-Leone (Case, 1998; Pascual-Leone & Goodman, 1979). Theoretical relations between Case's and Pascual-Leone's theory can be found in Pascual-Leone et al. (2010), Case (1998), and Morra et al. (2008). Another maturational-attention neo-Piagetian researcher who confounds maturational/endogenous mental attention (an executive-driven sort of attention) with working memory is Halford. Halford and associates (Andrews & Halford, 2011; Halford et al., 2007, 2014) have focused on how to assess the effort or memory load of their relational working-memory construct. They attempt this appraisal by estimating complexity only in terms of number of interrelated terms to be jointly considered in the task at hand. Their Relational Complexity Theory states that meaning occurs when a link is formed via interrelations (e.g., "cat" and "lion" are related because both are felines, and one is smaller than the other—two binary relations—and may also be related because "their particular trainer prevents the lion from attacking the cat"—a ternary relation). Meaning, and usually mental demand, accrue as higher-order relations (unary, binary, ternary, quaternary relations, etc.) are formed. However, Halford's relational complexity is not the only task-relevant sort of effective complexity. The mental demand of tasks can also accrue with other not interrelated but relevant relations, or pieces of knowledge, such as those that must be kept in mind for later use in a task. Nonetheless relational complexity is perhaps the most important aspect of knowledge, as Cassirer (1938, 1923/1953, 1929/1957) early emphasized.

For us, working memory can be best understood as a name for the working mind: a product of multiple causal-organismic factors that include maturational (endogenous) mental attention. Pascual-Leone is the founder of neo-Piagetian approaches and initiator of the maturational attention group of theories (Pascual-Leone, 1970; Pascual-Leone & Baillargeon, 1994). As mentioned, the TCO adopts the viewpoint of subjects' own processes: a metasubjective perspective (Pascual-Leone & Johnson, 2017). Within this theory, behavior is generated by mediation of various general-purpose hidden operators, or information-free brain resources (mental attentional effort, the field factor of simplicity, learning mechanisms, and other resources), which modulate the activation and functioning of self-propelling schemes. All this is governed by the principle of Schemes' Overdetermination of Performance (*SOP*), which dynamically/automatically synthesizes performance out of activated schemes (Pascual-Leone, 1970, 1987, 2014; Pascual-Leone & Johnson, 2005, 2017). As first formulated by Pascual-Leone (1970), mental-attentional capacity (*M-capacity*) increases (in its behavioral measure) every other year after the age of 3, reaching a limit of seven units at 15 to 16 years (this count of seven is obtained only when all necessary schemes, figurative as well as operative and their essential parameters, have been counted, if they are not boosted by some other resources such as affect or learning). This maximal *M*-capacity of seven is also found in adults (Miller, 1956), although adults often use a capacity of four or five, unless highly motivated and challenged (Cowan, 2005, 2016; Cowan, Ricker, Clark, Hinrichs, & Glass, 2015).

Although these issues are discussed in detail in the chapters to follow, table 1.1 and figure 1.1 give an overview of the TCO as coordination of hidden *resource operators* that apply to various kinds of action and executive schemes activated by the situation, to lead them to overdetermine (*SOP*) and cause performance and perhaps to change (adapt, learn) the schemes in question. Table 1.1 (discussed in detail in chapter 7) presents the organismic (hidden) resource operators of the working mind as processes in the brain. They are listed in a plausible order of their evolutionary emergence.

Figure 1.1 sketches diagrammatically how these operators codetermine functioning and adaptation of all types of schemes (executives, operatives, parameters, figuratives) and thus control *SOP* results. Operative schemes stand for processes that produce transformations and operations, mental or behavioral acts. These operatives can be ordinary action schemes (e.g., a grasping action blueprint) or executive schemes, which carry plans and regulate action schemes and hidden resource operators. Figurative schemes stand for the "objects" (psycho-*logical* entities, usually distal objects that in logic may be called "arguments") on which operatives apply (e.g., I see the piece of banana—figurative scheme—and the view elicits in me a desire to grasp and eat it—operative schemes). Parameters are a sort of relational figurative that stipulates the suitable conditions for operatives applying on figuratives (e.g., the banana looks too ripe for eating, so I resist taking it).

Critical Realism of Piaget and Cognitive Science

Constructivism appears as a "middle way" between rationalism and (meta-) empiricism. It produces operative/procedural and figurative/declarative models with the coordination of schemes and schemas active in the working mind. This is a result of organismic construction, based on perception, mentation, actions, and feedback from actions. However, Piaget defined schemes solely in terms of their *operating* (action)

Table 1.1
TCO's hidden operators listed in order of their likely evolutionary emergence

Operator	Description	Main Brain Region
A	Set of **affective** processes that intervene in motivation and attentive arousal.	Brainstem, hypothalamus, extended amygdala, limbic system
C	Both the process of **content** learning and the schemes derived from associative content learning.	Thalamus, Brodmann primary and secondary areas
F *(SOP)*	The **field** operator, which acts as a binding mechanism in the brain and brings closure to mental representations in a neo-Gestaltist manner. It often functions intertwined with the principle of Schemes' Overdetermination of Performance (SOP)	All areas
LC	The process of automatized **logical-structural** learning derived from ***C*** **learning** through overpractice.	Right hemisphere (RH)
T	**Temporarily** and effortlessly collates **sequences** of figurative schemes, thus facilitating the coordination that constitutes distal objects.	Hippocampal complex, occipito-temporal cortex
S	Effortlessly coordinates relations of coexistence among activated schemes, during operative activity (praxis). It, thereby, facilitates emergence of **spatial** schemes or schemas.	Hippocampal complex, occipito-parietal cortex
LA, B, LB	**Psychosocial and self-schemas** (*B*). **Logical-structural** learning primed by strong **affects** (*LA*), or by the personal **being** preferences—including emotions (*LB*).	Limbic system, orbito- and medial prefrontal, inferotemporal, medial parietal cortex
I	The attentional **interrupt**, which corresponds to the power of central active inhibition of unwanted schemes activated in the situation.	Prefrontal, RH-medial cortex, dorsolateral cortex, basal ganglia, thalamus
M	**Mental** attentional capacity of the individual.	Prefrontal, lateral, and dorsolateral cortex; basal ganglia; thalamus
LM	**Logical-structural learning** caused by the effortful use of **mental** attentional capacity	Left hemisphere tertiary areas, polymodal
E	**Executive** schemes in the person's repertoire, for the task at hand.	Prefrontal, lateral, dorsolateral, and frontopolar areas

Adapted from Pascual-Leone, J. & Johnson, J. (2005). A dialectical constructivist view of developmental intelligence. In O. Wilhelm & R. W. Engle (Eds.), *Handbook of understanding and measuring intelligence* (p. 181). CA: Sage. Copyright 2005 by Sage.

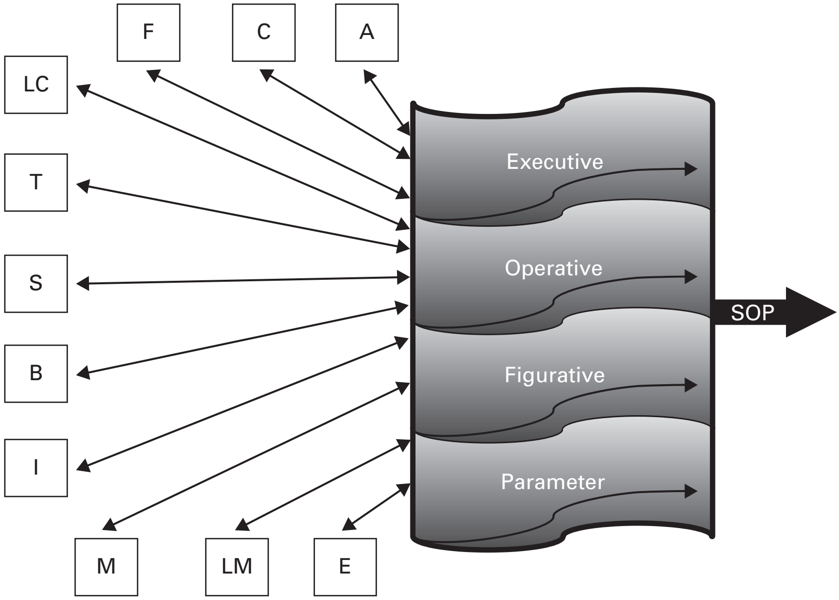

Figure 1.1
Theory of Constructive Operators (TCO) overview, with key organismic hidden-resource operators that can apply on various sorts of schemes, which in turn apply in coordination to synthesize/codetermined (*SOP*) the overt or covert performance. Parameters are figurative (representational) schemes that stipulate relations between operative (procedures) and figurative schemes. (Adapted by M. Arsalidou from Arsalidou, M., Pawliw-Levac, M., Sadeghi, M., & Pascual-Leone, J. [2018]. Brain areas associated with numbers and calculations in children: Meta-analysis of fMRI studies. *Developmental Cognitive Neuroscience, 30*, 246, CC-BY.)

components, often ignoring their *releasing component* (their cuing-features or conditions). For instance, when I see the brown, mushy flesh of a banana, a figurative aspect of the context or local reality, these characteristics automatically induce the working mind to expect the banana to be overripe. Mobilized scheme processes (figurative and at times also operative) serve as cues. B. F. Skinner with his operants (Catania & Harnad, 1988), like Piaget, also focused mostly on action components, segregating figurative aspects or releasing conditions of schemes as "discriminant stimuli"—aspects of the Real situation, as learning/memory theoreticians often do. There is a major constructivist problem when schemes are defined without reference to explicit releasing conditions, however. Unless conditions exist in the scheme that make it context-sensitive (thus producing *situated* knowledge), schemes would be released by any situation and thus should often fail to apply successfully. This would lead the scheme not to appear as a functional invariant likely to succeed when applied. Such unreliability, or functional deterioration, of the potential invariant would make it not (or much less) learnable, having failed its regularity as functional invariant. Organismic schemes emerge in the person's activity as we internalize encountered Resistances from actual Reality (see chapter 5). With the growth of cognitive learning, one's models of reality (coordinated packages of schemes) internalize progressively more, and more refined, resistances, becoming *viable* (pragmatically true) when used in agency or praxis (i.e., willful agency).

Because knowing (epistemology) and Reality (ontology) are so functionally intertwined, causality can be seen (Inhelder et al., 1977) as an attribution of empirically grounded psycho-logical operations to material objects—models that help to constitute the subject's representation. Causality must "be found in some manner as an objective and external reality" (Apostel, in Inhelder et al., 1977, p. 63; translation by JPL). In his reply to Apostel, Piaget agreed: "Indeed, when one arrives to true theories, it is because the object allows it [i.e., Reality constraints affect a subject's operating]; to say it in other words: the object already contained something like my operations [i.e., Piaget's models]" (Piaget, in Inhelder et al., 1977, p. 64; translation by JPL). Piaget, however, never said clearly what this "something like" is. He may not have worked out how causal coordinations (when true) embody relational task-relevant packages of Reality resistances. Learned low-level scheme packages serve as referential domain for more encompassing, higher-level abstractions. Often high-cognitive knowing is abstracting (according to Piaget) not from external reality/Reality itself but from the subjects' own actions or mentations (mental operations). Both ways of abstraction coordinate recurrent probabilistically invariant relations as patterns of activity, which emerge as schemas/structures that take as content abstracted schemes from lower levels, to generate flexible hierarchies. Such is the process of *reflective abstraction*, whose function is to restore adaptive equilibration in the working mind.

Resistances and Two Forms of Accommodation

As emphasized by Peirce, William James, and many others, knowledge has a practical aim: to serve in agency (or praxis—goal-directed activity addressed to the environment). It must embody (usually after progressive approximations, trial and error) the essential constraints (resistances—encumbrances, difficulties, or affordances) that Reality, in each particular type of situation, imposes on our agency. Cassirer (1940/1996) aptly described these resistances as such: "We experience something that stands in opposition to us, which is different from us, and out of this opposition grows our experience of the 'object'" (p. 140).

In fact, from a constructivist perspective, it is useful to think of reality/Reality as a universe of resistances (some sort of patterning that intertwines, e.g., essential characteristics and experiential outcomes) that emerge with the individual's activity in specific situations. Neither Piaget nor cognitive scientists have considered this idea enough. Resistances often have dependency relations among themselves (e.g., when I hit the *correct* pedal the car accelerates, *if* it is running *with* enough gas). Thus reality/Reality is populated by packages of interdependent resistances that may be somewhat different for each biological species. These resistance packages can be interpreted, without falling into empiricist excesses, as indexing recurrent patterns, that is, real complex functional invariants that emerge conditional to specific activities (Gibson, 1979; Nozick, 2001; Ullmo, 1967). The individual can cognize and relate these relational aspects of reality to other invariants, forming valid representative packages that probabilistically maintain invariances of mutual interdependencies of one to another resistance. Examples of such packages are complex *distal objects*, objects that emerge as invariants in the context of life-related praxis, such as cars, people, movie theaters, airports, universities, and so on. When such complex resistances (or packages) are helpful in current praxis, they generate *affordances* (Gibson, 1979). When they are a hindrance, they emerge as *encumbrances* or obstacles. Motivation (the conversion of affective goals into cognitive goals) leads the person to attend to, and internalize, such resistance packages, eventually causing people to have internal models (representations) for what Tolman and Brunswik (1935) called the *causal texture of the environment*.

Piaget used the term *accommodation* for adaptive incorporation of new reality/Reality features into a scheme. He called *assimilation* the application to experience and to reality/Reality (including subjective processes) of schemes already available to the subject. For Piaget, accommodation is always secondary to assimilation: accommodation takes place only when assimilation fails.

This assertion suggests that Piaget did not quite understand the cognitive dialectics of resistances, serving to internalize the causal texture of an animal's environment. Although *Piagetian accommodation* is real and important (a sort of accommodation that is *secondary* because it follows the failure of assimilation), it does not explain all constructivist learning. There are other ways to internalize resistances relevant to optimizing equilibration. There is also a limited *primary accommodation function* (we call it *Gibsonian*, because it was tacitly introduced by J. J. Gibson). It is primary because it occurs without assimilation (in Piaget's sense) and is limited because it is restricted to the concrete here-and-now. Gibson used wine tasting as an intuitive example to illustrate this sort of primary-accommodation learning, which he called *differentiation*. When one begins to taste wine, it is difficult even to distinguish between some red and white wines. Then, with practice, one learns to recognize kind, origin, and grape of many wines and begins to understand the language experts use to describe wine qualities. Because initially there is no discrimination, and this learning occurs with repetition but without feedback, differentiation learning must be the result of primary accommodation, not secondary.

In primary accommodation the lower central nervous system makes discriminations that are not initially passed to higher central nervous system areas (sites of the conscious/preconscious psychological organization). New information comes to the sensorial organs and is received and processed by the brain outside consciousness. As the experience repeats itself, however, the cortex may extract a functional invariant that is progressively moved from lower to higher brain processing areas until it eventually enters the psychological levels, potentially emerging into consciousness. This emergence constitutes a scheme resulting from primary accommodation, because information entered the brain and was abstracted via accommodation as an invariant before it could have been assimilated by psychological schemes.

Without primary accommodations, the refinement of affordances or encumbrances, or many truly novel insights about reality, would be impossible (due to the overlearning of competing schemes that become habits). Optimizing equilibration requires also primary accommodation. This view is consistent with the idea of two sorts of information processing, empirical/physical versus relational/conceptual (Piaget's empirical versus logico-mathematical experience), which often work together and become intertwined. As Langevin, a French physicist, claimed, much of the concrete "is nothing but overused abstract" (Ullmo, 1967, p. 637; Goldstein & Sheerer, 1941).

Organismic-Causal Processes of Working Memory Are Those of Working Mind

Moscovitch (1992) raised the important point that working memory is a process of "working-with-memory," a purely functional capability of memory. It is not a working space (often equated with consciousness, e.g., Dehaene, 2014). Moscovitch made a clear attempt to explain working memory in terms of organismic-causal processes (brain resources) that, in their interaction, produce the functional complex described as working memory. Moscovitch sharply distinguished between specific, more or less automatic (reflex) content- or action-processing *"modules"* (which are low-cognition analyzers or processors, e.g., hippocampal and sensorial functions) *versus "central systems"* (located in prefrontal lobe and related brain areas), often open and accessible to consciousness. The latter organize (i.e., coordinate) related content data obtained from local modules. He also made clear that working-with-memory is a product of procedural-representational central systems, which in the brain often involve prefrontal lobes.

Moscovitch did not, however, present a from-within (metasubjective) organismic-causal model of the working mind that produces this working-with-memory function. To formulate such processes one must differentiate two distinct sorts of functional systems: those serving as information carriers (the information-bearing and context-bound units that we call *schemes*: i.e., schemas, chunks) versus information-free and general-purpose system resources that we call *hidden operators and principles* (such as *SOP* discussed above). Hidden operators express "hardware" constraints, regulations of our brain as an organized functional totality. As already mentioned, this includes automatic/perceptual attention, mental/executive attention, content/associative learning, constructivist/structural/conceptual learning, neo-Gestaltist field factor, and so on. Researchers often conflate these two sorts of organismic-causal processes. As a result, they mistakenly equate mental/endogenous attention with working memory. In our view mental attention is indeed a key maturational constituent of working memory. However, working memory is a broader functional complex constituted by the coordination of mental attention with the repertoire of ordinary schemes and executive schemes; this coordination serves the working mind.

In the remainder of the chapter we briefly illustrate how our constructive-operators model can with advantage explain complex cognitive tasks involving working memory. Our example is the Raven Matrices Test of fluid intelligence (Gf)—a task that could not be explained well with constructs such as "modules" versus "central system" processes, or with more traditional conceptions of working memory. Heitz, Unsworth, and Engle (2005, p. 74) have expressed this lack of clarity: "The most puzzling realization is that we have good reason to implicate attention in Gf, but we are devoid of a suitable explanation for how attention comes into play when performing a task such as the Raven."

Figure 1.2 shows an adapted version of Raven's item C7 from Skuy et al. (2002). In all problems of this sort there is a matrix of figures (upper part of figure 1.2), each of them related to others by distinct relational patterns that run over the figures. One figure from the matrix is missing, and participants must choose from a sample of possible figures (lower part of figure 1.2) the one to best fill the missing slot. Doing so requires analysis of invariant patterns running over figures, to identify the matching one. In the more difficult Raven's items, to identify the missing part, participants must analyze into schemes (figural/relational pattern schemes) the perceptual features and dimensions of variation from every row, column, and at times diagonals, of the item's matrix.

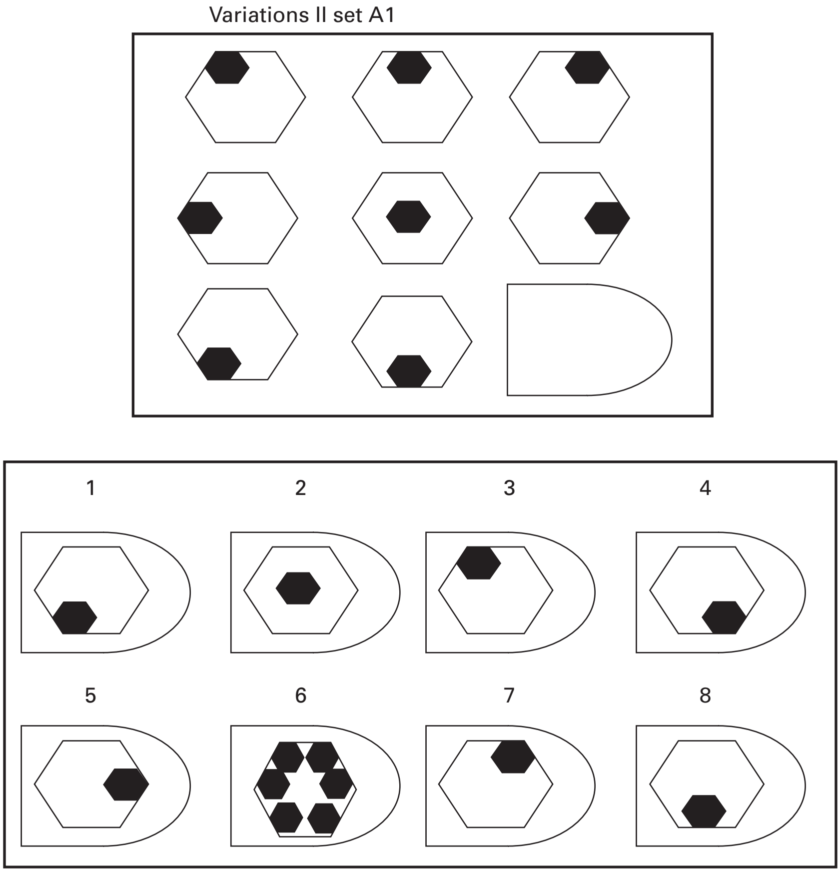

Figure 1.2
Variation on Raven's item C7. (Adapted from *Intelligence, 30*[3], M. Skuy, A. Gewer, Y. Osrin, D. Khunou, P. Fridihin, & J. P. Rushton, Effects of mediated learning experience on Raven's matrices scores of African and non-African university students in South Africa, p. 12. Copyright 2002, with permission from Elsevier.)

Sometimes a second dimension of variation is found on the rows or columns of the matrix, rather than in the diagonals, giving rows or columns two concurrent dimensions instead of one. Participants must identify simple or complex features (f_i, f_j, etc.) that for each dimension constitute a relational figurative invariant characteristic of this dimension, found in the appropriate cells. Such relational invariant makes mutually congruent (a correspondence rule) the various patterned objects within the figures (cells in the matrices) that concretely make up the dimension in question (instantiating its correspondence rule as a concrete token case). This is done via perceptual-cognitive analysis conducted successively for each required dimension[3] and then held in mind. An operative/procedural scheme of general synthesis (OPΣ) then recursively integrates the invariants of all dimensions to produce (via overdetermination) the pattern corresponding to the missing part.

Figure 1.3 outlines generically a possible case for these dimensions of variation. Note that we show OP3 in only one column. This represents a possible need to process a second dimension on the columns (not needed to solve the presented item). Were a second dimension present, as in more difficult items, OP3 would apply on all three columns. The actual process of dynamic problem solving could be roughly expressed by the following formula:

$$\underline{OP\Sigma}\ (\underline{OP4}(\underline{OP3}(\underline{OP2}(\underline{OP1}(\underline{PER{:}f_i,\ f_j}\ ))))) \qquad \textbf{(f1)}$$

Here operative processes (OP1, OP2, etc.) for the various relevant dimensions apply, to the right, on the products of previous operations. Notice that "PER:f_i, f_j" is the local perceptual process that Moscovitch may arguably identify as a module; the various OPs in contrast, and their coordination/organization, are the mind's inferential processes that Moscovitch may call central-system's work. But here we are assuming that these are schemes flexibly organized in hierarchies of various levels of processing. The order of operative processes could vary, but to complete the problem, all dimensions must be analyzed to extract or abstract their features' invariant; and these relational features are synthesized by OPΣ into the solution pattern. Against this final synthesis there are factors working: feature saliency differentials (often due to the neo-Gestaltist field or *F*-operator and to familiarity or due to logical-structural associative learning, which we call *LC*-operator). Misleading aspects of these feature-cues could make it harder to identify relevant dimensions of variation. The misleading factors are controlled by means of mental-attentional activation (our *M*-operator) and mental attentional inhibition (our *I*-operator). This is an *operative model* for the task solution. If we now count in the formula the number of schemes involved, we find at least six distinct symbolic/mental processes to be boosted with *M* and coordinated (we have underlined them in formula **f1**). This is the count for a complex Ravens item with four dimensions of variation. Items vary in the number of necessary dimensions. The item illustrated in figure 1.2, for example, could be solved by examining just two dimensions. However, all items require examination of rows and columns (and at times diagonals).

This is a sketch of operative task analysis conducted from within the participant's processing (metasubjective analysis). A complementary alternative way of doing analysis (meta-empiricist task analysis) would seek only to identify relational figurative features and their perceptual-rule patterns relevant in the test as a whole (and instantiated in one or another item). This would be an *objective* analysis focused on the relevant

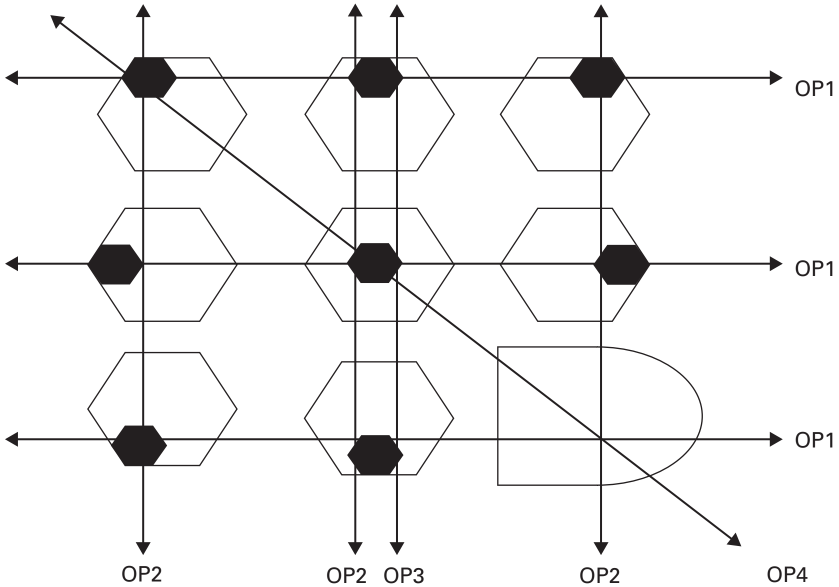

Figure 1.3
Dimensions of variation in solution of Raven's-like item. OP stands for an operative process to extract a dimension of variation across the figures. (From Pascual-Leone, J., & Johnson, J. [2017]. Organismic causal models "from within" clarify developmental change and stages. In N. Budwig, E. Turiel, & P. Zelazo [Eds.], *New perspectives on human development* [p. 82]. Cambridge University Press. Copyright 2017 by Cambridge University Press.)

figures of items, that is, a *figurative model*. Mindful use of these two complementary models helps participants to select the missing part of the matrix.

The TCO draws a sharp contrast between determinants of automatic/perceptual attention and those of mental attention—but this is a distinction among hidden operators, not between modules versus a central system. Piaget and other constructivist-learning researchers ignore mental attention as a distinct and independent cause of scheme activation. They attempt to explain mental (endogenous, focal, or executive) attention as being caused by the schemes' own assimilatory tendency (activation potency) and by cognitive learning. This formulation confounds processes of mental and perceptual or automatic attention. In contrast we see endogenous focal/mental attention as a main determinant in the working mind (working-with-memory) process—a determinant causally distinct from the repertoire of schemes.

Unlike Piaget, who only had one complex learning mechanism (i.e., structural learning), we have in our theory several categories of complex learning. We summarize these various learning categories now and provide more detail in chapter 5. The simple associative learning mechanism we call *C* learning (i.e., content-domain learning, playing the role of modules in Moscovitch's theory). We also have *LC* learning, which subsumes associative-structural learning—Piaget's logical-mathematical experiences when they are overlearned and occur in facilitating situations. *LC* learning takes place slowly, structuring together invariant associative-learning connections. The automatization (i.e., habits) that *LC* learning provides is useful in facilitating situations (when no misleading overriding schemes are found).

A selective and effortful dynamic synthesis of logical structures is necessary in conflict or misleading situations (when interfering schemes must be inhibited to solve the task); in this case, the power of mental attention (*M* and/or *I*) becomes necessary, as illustrated with the Raven task. This sort we call *LM* learning. There are multiple sorts of *LM* learning. They express different levels of *M*-capacity demanded by misleading tasks to be solved (see chapters 3 and 7). This requires progressively more *M*-capacity that grows maturationally with chronological age in normal children. Even when the needed executive know-how is available, a subject's level of mental (*M*) capacity must be commensurate to the task's *M*-demand, for the task to be solved easily. The *M-demand* of a task corresponds to the minimal amount of *M*-capacity needed to solve it. Because *M*-capacity has a maximum that increases with each developmental stage (the substages in Piaget's theory), each new stage enables children to cope with tasks of greater *M*-demand relative to previous stages. The maximum order/level of complexity-coping (or *M*-power level) that individuals' new *LM*-learning repertoire requires tends to increase with developmental *M-stage* levels (e.g., Arsalidou et al., 2010; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2005). These *M* levels determine effective complexity of truly novel tasks that an age group or person can solve—a major individual-difference variable.

Competition among schemes occurs in misleading or distracting situations. Piaget (1974, 1975/1985) talked about affirmations versus negations (i.e., opposite schemes) and about how these opposites must be numerous and in equilibrium to permit good adaptability (equilibration). This makes easier equilibration of dialectical opposites (such as subject's *M*-power versus task's *M*-demand, or schemes that contradict one another) within situations. As Heraclitus (2001 [46], p. 31), the old dialectical genius, said, "From the strain of binding opposites comes harmony."

The Working Mind

Meaning and Mental Attention in Human Development

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