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Chapter 2

Competence, Procedures, and Hardware: Conceptual and Empirical Considerations

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What is competence? There are two necessary features of competence that require recognition at the outset of any discussion. First, competence is a type of explanation, not a type of description. A competence explanation is characterized by being normative and abstract. *Competence* refers to an idealization of the organization, pattern, design, form, or structure of the event or system being explained. Thus, competence is explanation from pattern or design.

The second essential feature of competence is that it is one among several types of explanations that enter into scientific inquiry. Competence is introduced into scientific discourse to explain the relatively stable, enduring components of the domain under examination (Overton, 1985, 1990; Overton & Newman, 1982). It does not explain how competence is accessed and implemented. It does not explain the origin of competence itself. Answers to these latter questions require process explanations, procedural explanations, and neurobiological explanations. A complete scientific explanation of behavior needs the totality of several types of explanation, including competence explanations.

In this chapter I locate competence as an explanation within the context of contemporary empirical scientific discourse. In this effort I clarify the nature and value of competence explanations and demonstrate their necessary relationship with other types of scientific explanation. Following discussions of the place of competence in scientific discourse, and the relationships of competence to other forms of scientific explanation (i.e., procedures, hardware, and process), I describe some findings drawn from my own research project on the development of deductive reasoning. I hope this serves as an empirical example of the heuristic value of a developmental competence-procedure approach to our understanding of developmental phenomena.

Chandler (1987) has described an important isomorphism between the history of philosophy's understanding of the nature of knowledge, and the development of knowledge in human ontogenesis. This isomorphic sequence Chandler presented as stations of epistemology. The sequence serves as a base for a further elaboration into stations of scientific knowing. At the initial station described by Chandler, both philosophical thought and the individual organism hold a naive realist position. This *objectivist* epistemology lives by the claim that "seeing is believing" and asserts that sufficient observation will yield a fixed, absolute, objective "Truth" that exists independently of the mind. The second station continues to hold to the objectivist standard but accepts the fallibility of naive and time-limited inspection. Here, "seeing" is clouded by illusion, rumor, prejudice and other "errors." Tools of logic and time are needed to sort observations into the illusory and "the real." This station is sometimes defined as *"historical" realism* (Overton, in press-a).

At the third station of epistemology, marked in philosophy by the emergence of *contemporary rationalism*, and in ontogenesis by early formal thought, the objectivist standard is abandoned. Realism is rejected in favor of a recognition that all human knowledge derives from the human activity of interpretation (Overton, in press-a). This dawning awareness of the person-relative quality of human knowledge tends initially to lead to choices that cycle between skepticism, marked by a belief in the complete uncertainty of all knowledge, and dogmatism, marked by the belief that there must be some omniscient source of truth that resides outside human interpretation.

As the rationalist position develops it leads to the fourth epistemological station that Chandler called *post-skeptical rationalism*. Here, recognition that all knowledge is constructed knowledge—and hence, never absolute—moves beyond skepticism-dogmatism to a strategy of asserting that arguable good reasons, developed in the context of agreed upon knowledge criteria, can function at various levels of plausibility as a system for choosing one belief or one action over another.

STATIONS OF SCIENTIFIC KNOWLEDGE

These four stations of epistemology have strongly influenced the development of stations of scientific knowledge (see Overton, 1984, 1985, in press-a; Piaget & Garcia, 1986), and it is in this specific arena that the question of the scientific legitimacy of competence type explanations becomes evident. The first station of scientific knowledge corresponded to the epistemology of naive realism, and was called *positivism*. As a strategy designed to distinguish scientific knowledge from other knowing activities, positivism held that to be properly scientific any explanatory statement must be an empirical generalization induced directly from observation, and must be demonstrably capable of being reduced to observation.

The force of positivism's criterion of science was to warn the aspiring scientist—on penalty of being branded nonscientific—to avoid speculation and interpretation, and to swear fealty and devotion to description and direct observation. Not only did this station require that explanation both temporally and logically follow complete description, but explanation itself, as a generalization inductively drawn from direct observation, of necessity, had to be composed of only observationally based antecedent-consequent functional statements. Thus, explanations became known as empirical generalizations.

Conventionalism constituted the second station of scientific knowledge. This strategy for distinguishing science from other types of knowledge conserved the realist objectivist tenets of positivism. However, conventionalism recognized that not all features of theory could be reduced to direct observations. As a consequence, conventionalism agreed to admit nonreducible features of theory into the arena of legitimate science. But theory so defined was also understood to function only as a means of arranging the hard data of description. Thus, theories or models came to be thought of as heuristic devices that should fade in scientific importance once time and observation had led to explanatory laws based on inductive generalizations from the reality of hard data. Under this interpretation, legitimate scientific explanation remained tied to inductive empirical generalizations drawn from direct observations of antecedents and consequences.

At both of the realist objectivist stations of science a rigid distinction was maintained between theory and data, interpretation and fact, explanation and description. And it was offered as an absolute necessity that data, fact, observation, and description constituted the court of final appeal for scientific merit. This attitude engendered various methodological slogans designed to keep investigators on the path to absolute, objective Truth; "if you describe carefully enough, explanation will take care of itself," "stay close to the data, avoid speculation," "see what the data tells you," "interpretation must await further data," "we need local explanations, not universal explanation," "explanations must be tied to observables either as intervening variables, or as hypothetical constructs."

It is clear that at these realist scientific stations there has been no room for pattern or competence explanations as legitimate scientific explanation. If "competence" is even introduced at these stations it is only used to suggest that the investigator has unearthed some faint glimmer of an otherwise obscure ability hidden by measurement error. According to this interpretation, competence merely points toward an underlying ability that constitutes the reality, and that will be directly observed and described once the debris of error is cut away.

The third station of science emerged out of a renewed focus on rationalism or *interpretationism* as a viable epistemological approach. Although rationalism has a history as ancient as realism (Overton, in press-a, in press-b), its contemporary impact on science is marked by the work of Norwood Russell Hanson (1958). Hanson developed the influential argument that all data, including the data of observation, are "theory laden" (i.e., necessarily interpretative), and the corollary argument that *explanation in science involves discerning patterns rather than observing cause-effect sequences*. This argument erased the realist's clear distinction between descriptive facts and interpretations, and reintroduced pattern or competence as legitimate scientific explanation. Following from Hanson's work, Kuhn (1962, 1977) presented his now famous thesis that at every level science is controlled by interpretative paradigms and these paradigms pervade both observational data and the methodology of theory choice.

By establishing interpretation as basic to and inherent in the scientific enterprise, this station of science opened up the door of relativism, and as with the underlying epistemological station, a *skeptical-dogmatic* axis soon developed. The skeptical pole was established by Feyerabend (1978) who made radical relativism a scientific virtue. If the human activity of interpretation is a nondissectable feature of science—so the argument goes—then there is no basis for making judgments of good or bad interpretations. My interpretation is as good as yours because there are no absolute, objective criteria for deciding between judgments. Hence, "anything goes" in science as it does in other forms of knowing.

Indeed, as skepticism progresses it becomes increasingly difficult to discriminate empirical science from any other knowing activities. As a result, this pole moves through phases of its own line of development from empirical to hermeneutic science, to narrative and rhetorical knowing, to reconstructionism and deconstructionism, and into postmodern thought (see Overton, in press-a). With each new phase the skeptical pole asserts its antifoundational spirit and advances toward solipsism. An important corollary of this movement is that all types of universals are increasingly devalued in discourse because they appear to evoke the ghost of some transpersonal order that has been rejected. Thus, the historical, the contingent, the particular gain a privileged status in this system that asserts that there is no privilege. In this atmosphere there is no room for the abstract, the normative, and hence no room for competence.

In the face of the specter of on rushing solipsism, the dogmatic pole of the skepticism-dogmatic axis has arisen as a renewed faith in the methods-of-science. "Scientific method," like a religious sacrament, is accepted as the unquestioned means for achieving ultimate certainty. This amounts to a form of neo-positivism with an insistence on the absolute priority of particulars, observation, description, analysis, and induction (see Siegler & Shipley, 1987; Sugarman, 1987a, 1987b). As Kessen (1984) has pointed out this "zest for analysis and for particulars may lie close to the center of American psychology's unspoken creed" (p. 11).

As rationalism has generated a skepticism–dogmatism axis, it has also established the context for moving forward to a post-skeptical station of empirical scientific knowledge. At this fourth station, the argument that all knowing emerges out of activity forms the point of origin for any inquiry into the possibility of constructing arguable good reasons as a foundation for a relatively stable, coherent, consistent, and plausible system of empirical scientific knowledge. The writings of Lakatos (1978) on scientific research programs, Laudan (1977, 1984) on scientific research traditions, Putnam's (1987, 1988) exploration of meaning and meaning holism, and Dennett's (1987) and Marr's (1982) analyses of strategies of scientific explanation all represent significant components of this effort.

The post-skeptical rationalist station of science begins—as do all the stations of science—in the commonsense actual or manifest world (Overton, in press-a; Sellars, 1963). This manifest world is the conceptual lens that we, merely through being human, employ in day to day life. Like all other stations, this one also takes as its general aim the establishment of order and organization in the chaos of contradictory experiences that emerge in this manifest world. And like other stations, this one also brings about order and organization through explanation. Thus, at all the stations of scientific knowledge science moves from the manifest image of man-in-the-world to the scientific image of man-in-the-world. However, at this rationalist station order is not established by ever intensified micro-observations and micro-descriptions designed to uncover absolute, objective, fixed functional relationships that will yield inductive universal generalizations as explanations. This realist strategy has been abandoned.

At the fourth station of scientific knowledge order is brought about by constructing *abstract patterns* that plausably, intelligibly, and coherently systematize the domain of inquiry. These abstract patterns, arrived at through abductive or retroductive inference process (interpretation), constitute the primary explanations of science. Causal laws are formulated within and derive their meaning from the pattern context (see Overton, in press-a). Pattern explanation avoids regression to skepticism-dogmaticism by being formulated and tested according to criteria that are explicitly recognized as the product of human discourse. These criteria have included scope of application, depth, logical consistency, fruitfulness, and empirical support.

If we now attend directly to the concept of competence, it should be clear that as abstract, normative, pattern explanation, this concept finds scientific legitimacy only at the scientific station of post-skeptical rationalism. Here, abstract patterns are not mere heuristic devices that temporarily substitute for real explanation, nor the symptoms of some hidden ability called competence.

Rationalism—or what Putnam (1988) called "internal realism" and Lakoff (1987) called "experiential realism"—establishes the context that lends scientific meaning to competence explanations. However, a more detailed analysis is needed to demonstrate the use of competence as psychological explanation, to illustrate specific features of competence, and to show how competence is related to other forms of psychological explanation. A first approximation to this effort, begins with the recognition that the primary types of explanation offered in any field have changed little since the general explanatory scheme proposed by Aristotle.

SCIENTIFIC EXPLANATION

Aristotle asserted that any phenomenon was completely understood only when four causes or explanations were offered for that phenomenon. These four consisted of *material* cause (that which the thing is made of), *efficient* cause (that which moves a thing), *formal* cause (the form or pattern of the thing), and *final* cause (that which the thing is directed toward) (see Overton, 1985, in press-a, in press-b). Material and efficient causes are particulars and, in principle, observable. It is for this reason, of course, that they are favored by any system that accepts the realist standards. They are also causal in the traditional sense of a cause as being something that produces something. Contemporary examples of material causes include the range of neurobiological factors such as genetic, physiological, and neurological factors. Contemporary examples of efficient causes include environmental, cultural, and situational factors.

Formal and final causes are abstract universals and thus, in principle, not observable. Both are pattern explanations. Formal causes define synchronic patterns; final causes define diachronic (developmental) patterns. These explanations are not productive in a causal sense, but rather, they are principles that introduce coherence and intelligibility. When reasons are contrasted with causes in schemes of scientific explanations, formal and final explanation constitute reasons. The structure of the atom, the structure of DNA, the structure of the solar system, and the structure of the universe are examples of formal explanation drawn from the natural sciences. Kinship structures, mental structures, mental organization, structures of language, ego, and superego, dynamisms, schemes, operations, and cognitive structures are formal explanations drawn from the human sciences. The second law of thermodynamics is a contemporary example of final explanation in the natural sciences. Piaget's equilibration process, Werner's orthogenetic principle, Erikson's epigenetic principle, and Margaret Mahler's individuation-separation process are final explanations in developmental psychology.

Today the labels have changed and the terms *material, efficient, formal*, and *final* are infrequently directly discussed. However, in contemporary theories of mind and in the cognitive sciences the surrogates of the four causes—"hardware" explanation, "procedural" (also "algorithmic" "functional" and "semantic") explanation, and synchronic and diachronic "competence" (also "pattern," "design," "syntactic") explanation—continue to frame the dialogue and the debate about what constitutes adequate scientific explanation. The most significant recent change in the four explanatory types is that they have come to be thought of as related levels of analysis from the hardware, to the procedural, to the competence level (see Dennett, 1987; Marr, 1981, 1982; Searle, 1984).

Within the competence-procedure-hardware framework of scientific explanation significant questions about the nature of mind have centered around issues of whether all levels are required for adequate explanation; whether a particular level might be eliminated or reduced to other levels (P.M. Churchland, 1981; P.S. Churchland, 1986; Dennett, 1987; Searle, 1984); whether the levels themselves are best formulated within the framework of a computer metaphor or an organic metaphor (Lycan, 1987; Overton, 1990, in press-c). Thus, for example, both P.M. Churchland (1981) and P.S. Churchland (1986) take an eliminative materialist position and argue that adequate explanation can be established at the neurophysiological hardware level, and other levels are reducible to this; Searle (1984, 1990) claimed that the procedural or algorithmic level is an unnecessary interposition between the physical and the mental levels; Dennett (1987) discussed the necessity of each of the levels. It should not be surprising that those who favor reduction to causal levels are the same individuals who continue to favor the realist scientific strategies described earlier.

FUNCTIONALISM AND SCIENTIFIC EXPLANATION

Before directly examining hardware, procedures, and competence as interrelated levels of explanation it is important to emphasize that these explanations are framed by a functional understanding of the nature of human systems of behavior and behavioral development. The explanations are all functional in nature. The patterns are *patterns of activity* and change, and the causal features attend to manifest or real-time processing in relation to inputs, outputs, and other internal states of the organism. These are all criterial features of contemporary functionalism. However, "functionalism" incorporates a variety of approaches (Garfield, 1988; Overton, 1984, 1990), and recently certain of these have come under increasing criticism (Garfield, 1988; Lycan, 1987; Putnam, 1988; Searle, 1984, 1990). The basic issue of concern is not functionalism itself, but the choice of underlying metaphor to guide further elaboration of the functionalist program.

Early functionalists in the time of William James and John Dewey drew their functionalism out of an organic metaphor. Functionalism was understood in terms of activity as it related to the inherent organization of the activity, function as related to its form or structure, adaptation as related to the forms of adaptation, ends as related to the means for their achievement. Later functionalists from the time of Angell, Carr, and Woodworth replaced the organic metaphor with the machine metaphor. Under the influence of a 19th-century physics that understood energy as being separate and distinct from structure, activity came to be understood as separate and distinct from organization, adaptation *produced* forms, activity itself was *caused by* inputs. Sometimes, as in the case of Watson and Skinner, the machine metaphor faded sufficiently into the background so that only the causal (functional) concerns with inputs and outputs were recognizable. At other times a variety of machines, from hydraulic systems, to telegraph systems, telephone switchboards, and finally digital computers have explicitly framed explanation. Today, critics of machine functionalism and a subspecies of machine functionalism called *psychofunctionalism*, are again urging the rejection of the machine metaphor (Lakoff, 1987; Lycan, 1987; Macnamara, 1986; Putnam, 1988; Pylyshyn, 1984; Searle, 1984, 1990) and a replacement by an organic metaphor (Johnson, 1987; Lakoff, 1987; Lycan, 1987; Overton, 1990).

The importance of a move to an organic metaphor as the guiding conceptual foundation for functionalism cannot be overemphasized. It is equivalent to—and in some ways identical with (see Overton, in press-b)—the move from the stations of epistemological realism to the stations of epistemological rationalism. It is only from this organic conceptual foundation that pattern explanation and causal explanation (structure and function) are joined into a unified meaningful whole. It is only from this vantage point that patterns establish meaning, coherence, intelligibility, and understanding while causality yields the pragmatics of analysis, implementation, and manifest plausibility. This type of meaning holism (Putnam, 1988) is the province of the organic, not the machine.

Organic functionalism requires hardware, procedures, and competence as an integrated organization of explanatory types. Hardware and procedures constitute the causal mechanisms according to which competence functions. The levels form a hierarchical system of explanation that is holistically regulated. Each level requires and interacts with the others but predictions made from any one level will differ from predictions made from another level.

COMPETENCE-PROCEDURES-HARDWARE

Competence refers to the design features of the system that is being explained. The investigator beings the process of explanation by asking the functional question of what the system is for. The answer to this question constitutes the general domain of inquiry and, with proper specification, it leads to the question of the design of the system that serves this function. For example, many theories of human development—including Jean Piaget's cognitive theory and John

Bowlby's social-emotional theory—assert that "adaptation" constitutes the most general function of the human organism. Adaptation is usually defined according to some interpretation of survival, and thus the theories align themselves with a more inclusive evolutionary theory. Having taken this stance with respect to the functional question, investigators further specify more circumscribed domains of the adaptation. Piaget focuses on the adaptational value of thinking that is coherent, noncontradictory, and precise (i.e., logical reasoning). Bowlby focused on the adaptational value of behavior that maintains or strengthens bonds of close interpersonal relationships (i.e., attachment). These circumscribed domains form the specific focus of the theory (i.e., the system of propositions that will constitute explanation). After addressing the question of what the system is for, the investigator turns to the question of the nature of the design or organization that serves this function. Here Piaget (Piaget & Garcia, 1986) proposed a design that has the character of a logic system and Bowlby proposed a design that is referred to as a "behavioral attachment system" (see Hinde, 1982; Overton, in press-a; Sroufe, 1977).

The design that the theorist articulates constitutes the competence in the domain in question. This is not a thing that exists in the head of the organism. Such a position would only be appropriate to the realist who believes that all explanation is description. Competence is a type of explanation that asserts that it captures organizational features of the organism in the domain under examination. For example, in the field of the development of logical reasoning (Overton, 1990), competence or mental logical theorists claim that the rules that have been derived by logicians to represent the structure of valid arguments may be taken as a relatively adequate *model* of the normative, idealized, abstract operations of mind in this domain. The model constitutes logical competence.

A particularly critical attribute of a competence model is that it predicts universal and necessary features of the domain under investigation. For example, in logical reasoning the competence model addresses questions concerning the organism's ability to comprehend or understand valid argument forms. It predicts the psychological availability of specifically logical (i.e., necessary and universal) features of deductive reasoning. Thus, with respect to the competence model itself, the developmental investigator can ask empirical questions about the adequacy of the particular model as a general representation of the organism's logical knowledge, about the developmental timing of the availability of this logical knowledge, about precursor forms of competence that approximate this competence.

The competence model does not, however, specify the particular details of how this design is accessed and implemented. Access and implementation are questions for the procedural model or procedural explanation. Russell (1987) captured this important detail when he pointed out that the competence is not to be regarded "as 'mental representations' that the adult thinker uses when he reasons, but . . . idealizations of the system of thought to which the 'normal adult' has access. Sometimes the access is good, sometimes poor'' (p. 41).

Competence thus necessarily leads to procedures, because procedural explanation offers explanation for *how* competence may be accessed, implemented, and expressed. And procedures require competence, because procedures operate as detached and empty causal mechanisms unless they are grounded in the meaning structure provided by competence (see Marr, 1981). If procedures are explored without reference to competence as they often are in experimental psychology, then we return to the standards of realist science with the hope and wish that some day in some way the generation of numerous causal mechanisms will inductively yield an explanatory synthesis.

Procedural explanation is offered to explain the manifest or real-time activities that access and implement competence. That is, procedures predict specific causal features of task solutions. As competence is directed toward understanding, procedures are directed toward successful task performance. As competence is relatively context free, procedures are context embedded. For procedural explanation the investigator proposes some algorithm or heuristic that mimics or imitates the organism's real time activity and this serves as a procedural model. The model is functional in nature in the sense that it identifies some token psychological state (e.g., logical reasoning according to truth tables) with some token behavioral state (e.g., actual truth table manipulation or some derived measure of this), or some token physical state (e.g., some neurophysiological state), and it is sensitive to inputs and outputs (e.g., the specific content of logical problems) (see Garfield, 1988).

Because the kinds of procedures that can be used to account for the access and implementation of competence are limited only by these functional criteria, the number of candidates for designation as procedures is large. If we again take logical reasoning as the domain of interest, it may be the case—as, in fact, proposed by various investigators—that the actual processing of logical problems takes place by reasoning in terms of truth tables (Osherson, 1975); by reasoning in terms of Venn diagrams (Revlis, 1975); by reasoning in terms of natural deductive procedures (Braine, 1990); by reasoning according to mental models (Johnson-Laird, 1983), by pragmatic methods (Cheng & Holyoak, 1985; Cheng, Holyoak, Nisbett, & Oliver, 1986), or by various methods employing direct experience (Griggs, 1983; Mandler, 1983). Further, procedures may reflect individual differences or individual strategies, and as a consequence, different people may at different times and under different circumstances use different procedures in the actual processing of logical problems. The empirical problem is not necessarily to choose among these alternatives, but to test, in the context of available competence, when and under what conditions the alternatives best facilitate logical reasoning.

The formal distinction between the competence and the procedural model is illustrated in the contrast between Dennett's (1987) presentation of the competence model as a "fictional notation system" and Craik's (1943) presentation of the procedural model as a "working model." About competence, Dennett (1987) stated:

> The idea of a notational world, then is the idea of a model—but not the actual, real, true model—of one's internal representations. The theorist wishing to characterize the narrow psychological states of a creature, or in other words, the organismic contribution of that creature . . . *describes* a fictional world; the description exists on paper, the fictional world does not exist, but the inhabitants of the fictional world are treated as the notional referents of the subject's representations. . . . (pp. 154-155)

On the other hand, in keeping with the actual internal representations of procedural models Craik (1943) asserted:

> By model we thus mean any physical or chemical system which has a similar relation—structure to that of the process it imitates. By "relation-structure" I do not mean some obscure nonphysical entity which attends the model, but the fact that it is a physical working model which works in the same way at the process it parallels. . . . My hypothesis then is that thought models, or parallels reality. (p. 61)

Although there is general agreement that procedures, as distinct from competence, must be modeled on actual or manifest real-time activities, Craik's limiting argument for a "*physical*" working model demonstrates an early commitment to the ideal of machine functionalism or psychofunctionalism where the test of the adequacy of a model rest on its ability to pass the test of the Turing machine. That is, within these types of functionalism a procedure is adequate or "effective" to the extent that it can be carried out by a simple machine.

Johnson-Laird's (1983) more recent work on mental models as "effective procedures" in the domain of logical reasoning is a contemporary example of a commitment to such a machine criterion of adequacy (see also Johnson-Laird, Byrne, & Tabossi, 1989). Johnson-Laird, in fact, proposed to limit psychological theory to just this test and just this level of explanation. As he said, "My proposed criterion for psychological theories is that they count as putative explanation only if it is possible to formulate them as effective procedures . . ." (p. 7). And, "My starting-point will be Craik's intuitive idea of an inner mental replica that has the same 'relation-structure' as the phenomenon that it represents" (p. 11). As stated earlier, this machine metaphor is not a necessary feature of functionalism and its use as a standard leads to an exclusionary stance with respect to explanation, and a consequent failure to consider a necessary interrelationship among levels of explanation. Macnamara (1986), who presented a type of organic functionalism in the domain of logical reasoning, argues that the very use of the term *procedures* is misleading: "A procedure is an electronic device that in the last analysis can be described completely in the language of physics. I do not call the mind's interpretative devices procedures but simply interpreters" (p. 35).

One of the most important reasons for keeping clear the formal distinction between competence (i.e., fictional notation systems) and the procedural (i.e., simulations of actual or manifest operations) models is that it highlights the often misunderstood fact that empirical tests designed to assess procedures do not count for or against any particular competence notation. For example, it is quite possible to conclude on the basis of empirical research that people rarely *actually* think in terms of truth tables. This counts against the plausibility of truth-table thinking as an effective procedure or interpreter. However, even if no one ever actually thinks in terms of truth tables, it is still quite reasonable to accept truth-table notation as the notation for the competence model of logical reasoning. The empirical test for the plausibility of the truth-table notation as an adequate competence model (see Smith, 1987) is quite distinct from the test of the truth table as a plausible procedural model.

The final and most particular level of analysis, is the *hardware* level. Here a physical strategy is employed and attempts are made to describe the physical mechanisms (e.g., neurophysiological mechanisms) that implement the design constrained procedures. Little needs to be said about this familiar level except perhaps to note that the term *hardware* itself derives from a machine metaphor and this level might perhaps simply be known as the neurobiological level of explanation.

DEVELOPMENT AND COMPETENCE-PROCEDURE-HARDWARE EXPLANATION

The one feature still missing from this account of the hierarchical relationship among competence, procedures, and hardware explanations is any statement of how such a scheme would incorporate a developmental or change dimension. There are several potential solutions to this problem. It could be assumed that the active processes that are instances of each explanatory type are built into the system. This is the classical nativist solution. Or it could be assumed that the processes themselves are directly acquired from the environment. This is the classical empiricist solution. Both of these solutions are, in fact, generated by the machine metaphor.

The organic functionalist solution to the explanation of development calls on the diachronic dimension of pattern explanation (the Old Aristotelian final cause). It is maintained that the active processes that correspond to each explanatory type (competence, procedure, hardware)—and hence, the explanatory types in their specific instantiations—become transformed across development. Each transformation marks major development phases. The transformation are ordered and explained according to some pattern. However, here the pattern and the process corresponding to the pattern, is progressive in nature (see Overton, in press-a). Pattern-progressive explanations are explanations of development itself, whereas competence, procedures, and hardware are explanations of what has developed at any point in the developmental series.

To illustrate the developmental explanation consider Werner's (1957) Orthogenetic Principle. This explanatory principle asserts that the pattern of all developmental series is from states of globability and lack of differentiation of parts, to states of increased articulation, differentiation, and hierarchical integration. The functional process that is the direct complement to this diachronic pattern explanation is found in Piaget's (1987) equilibration process—itself framed by an adaptational context. The equilibration process asserts that pattern differentiations and integrations are constructed through the activity of assimilation/ accommodation (Overton, 1989) and lead to increasingly adaptational patterns.

When this developmental explanatory scheme is applied to a particular domain such as logical reasoning it suggests that initially there is little differentiation at a psychological level between competence, procedures, and hardware. The initial state of the organism is understood as an organized system of biological activity. Psychological organization and processes differentiate out of this neutral matrix through the assimilation/accommodation activities of the organism. Thus, both competence and procedural systems initially emerge from the organized embodied experiences of the organism—a biological level of competence, procedures, and hardware. The initial psychological (sensorimotor) development is procedural in nature, but this develops in the context of the original biological competence and it results in the acquisition of the first psychological competence. At this level there is a logic, but it is a logic defined by organized activity, not reasoning.

As the developmental process proceeds, further differentiations and integrations lead to new more adapted states that are characterized as "representational" or "conceptual" (Overton, 1989, 1990). At this new level, novel competence and procedures again differentiate. Here, the competence pattern may be referenced by a class logic notational system or some other notation. Logical thinking becomes available but the logic is fragmentary in nature and does not permit generalized systematic inference across a network valid argument forms (see Markovits, Schleifer, & Fortier, 1989). At the next level of adaptive differentiation and integration, the acquired system can be characterized as a relatively complete predicate logic system and a system of procedures that access and implement this competence. This level is identified as the level of formal deductive reasoning.

Thus far, I have demonstrated that pattern explanation is required for a complete understanding of human functioning and human development, that pattern explanation finds true scientific legitimacy only at the post-skeptical rationalist station of science, that pattern explanation is thoroughly functionalist in nature, and that pattern explanation is a part of an integrated organization of explanatory types. In the final section of this chapter I present an overview of a specific empirical research program that has been formulated and conducted within this conceptual frame.

COMPETENCE PROCEDURES AND DEDUCTIVE REASONING: EMPIRICAL RESEARCH

For several years my students, colleagues, and I have been investigating problems related to the developmental availability of deductive reasoning competence, and real-time procedures that access and implement competence. Conditional ("If . . . then . . . ") sentences are central to deductive reasoning because they can express implication, and implication is the pivotal concept in any system of logic. Accordingly, reasoning with conditionals has been the focus of our research.

Our general working hypothesis has been that although there are early precursor forms of logical competence (i.e., a logic of action, a fragmentary class logic), the competence that permits fully systematic deductive reasoning does not become available until the adolescent years. Further, once available, a variety of real-time procedures may be required to successfully access and implement the competence. The idea of a systemic or systematic availability refers to the fact that deductive understanding (i.e., competence) involves a network of inference rather than being limited to only one or two specific types of inferences (see Smith, 1987). For example it may be the case that young children understand some form of the inference "If p, then q; p; therefore q." However, systemic deductive competence is in evidence only when this becomes the valid Modus Ponens inference rather than a promise, or a causal, or temporal sequence. This Modus Ponens inference, in turn, becomes a part of a network of inferences including the valid Modus Tollens ("If p, then q; not q; therefore not p"), as well as the invalid inference forms, Denied Antecedent ("If p, then q; not p; therefore not q") and Affirmed Consequence ("If p, then q; q; therefore p").

In an early series of studies, O'Brien and Overton (1980, 1982) examined availability (a competence issue) and the manner in which interpretation (a procedural issue) of the conditional "If . . . then . . ." sentence influences accessibility. In every day usage people may interpret "If . . . then . . ." sentences as causal, temporal, or biconditional ("If and only if") relationships, rather than as a relationship of implication. When the task is designed to evaluate the understanding of formal implication, the other types of interpretations yield the appearance of poor logical reasoning. However, the failure may be the product or poor access to the logical competence, rather than the absence of this competence.

These studies employed a contradiction training technique. Participants in Grades 3, 4, 7, 12, and college were presented with an incomplete conditional rule; "If a worker is ——— years of age, or older, then that person will receive at least $350 each week." Following the rule presentation, a series of 12 exemplars of ages and salaries were given (e.g., A 20-year-old who makes $50 per week; A 60-year-old who makes $600 per week). The task was to select, for each exemplar, what could be inferred about the missing age in the rule (i.e., "The age in the rule is more than . . . ."; "the age in the rule is . . . at most"; "Nothing at all").

During the early trials there is a tendency to make inference errors suggesting that participants fail to interpret the rule as a conditional. However, on the sixth trial, an exemplar was presented that directly contradicted such faulty interpretations. It was expected that this procedure would facilitate access, via interpretative procedures, to the appropriate logical competence for those individuals who had this competence available. The results of these studies demonstrated the availability of competence at Grade 12, and at the college level. At these age levels, the contradiction training successfully facilitated performance, and this enhanced performance generalized to other deductive reasoning tasks. The studies did not, however, show any evidence of the availability of competence at ages earlier than Grade 12, and this became an issue for later investigations.

The interpretation of the conditional sentence is a fundamental issue for procedural models of deduction. However, there are other classes of variables, both organismic and environmental, that also implicate real-time procedures. One of these is cognitive style. In an effort to analyze the role of cognitive style in accessing and implementing available deductive competence, an investigation was conducted with participants from Grades 8, 10, and 12 (Overton, Byrnes, & O'Brien, 1985). The contradiction training paradigm was again employed, but in this study the participants were also tested for Reflective–Impulsive cognitive style, by means of the Matching Familiar Figures test. As in the earlier research, it was found that the availability of deductive competence was in evidence at Grade 12, but not earlier. At this grade, contradiction training enhanced performance, and generalized to another deductive task. A reflective cognitive style was found to enhance performance at all age levels. However, for the generalization deductive task, the benefits of a reflective style were limited primarily to those who had demonstrated the availability of competence. Thus, it appears that once deductive competence is available, and interpretative procedures access this competence, a reflective cognitive style operates as a procedural support to further facilitate implementation of the competence.

The fact that the contradiction-training paradigm did not yield evidence of deductive competence prior to Grade 12 precluded any exploration of the role of interpretative procedures during childhood and early adolescence in these early studies. This led to a more direct exploration of the understanding of "If . . . then . . ." sentences, and precursors to such understandings. In order to claim a formal deductive understanding of "If p, then q" as an implication, it must be shown that the following are recognized: (a) that particular instances of the antecedent (p) and consequence (q) clause of the sentence are permissible; (b) that other instances are not permissible; and (c) that others are indeterminate. Specifically, given "If p, then q," it is the case that "p and q" is permitted, "p and not-q" is not permitted, and "not-p and q" and "not-p and not-q" are indeterminate. For example, with the sentence "If it has rained, then the grass is wet," finding an instance of "rain and wet" supports the truth of the sentence; finding "rain and not wet" falsifies the sentence' and finding "no rain and wet" or "not rain and not wet" yield uncertainty about the truth of the sentence.

An obvious precursor to a formal deductive understanding of implication is the understanding of the certainty and uncertainty of conclusions. Unless it is recognized that it is *certain* that "p and not-q" falsify the sentence, and unless this knowledge is coordinated with the certainty and uncertainty of the other instances, a formal deductive competence cannot be claimed. In an initial study (Byrnes & Overton, 1986), we examined the ability of children at Grades 1, 3, and 5, to draw certain and uncertain conclusions. It was expected, following Piaget's (1987) work on necessity, that concepts of certainty and uncertainty would first develop in nonformal concrete and causal contexts, and only later in formal deductive contexts. At each grade, the children's conclusions were evaluated in all three contexts. The *concrete* context involved a task requiring conclusions about whether objects would fit into openings in a box, the *causal* context a task requiring conclusions about pictured causal sequences, and the *formal deductive* context conditional syllogisms.

Our predictions were supported, and we found that an understanding of, and discrimination between certain and uncertain conclusions is mastered in concrete and causal context by Grade 5. However, this understanding is just beginning to emerge at Grade 5 for formal deductions. This is consistent with Piaget's position that formal competence begins to become available around 10–12 years. If this is the case, it appears that the next several years may be a period of consolidation for the formal competence, which only then demonstrates systemic availability.

In the next study (Byrnes & Overton, 1988), we focused more specifically on the understanding of "If p, then q" as a formal implication. Participants at Grades 3, 5, 8, and college level were evaluated with several procedures designed to elicit understanding of the coordination between permitted and nonpermitted instances of formal application, and distinction between the conditional and other propositional types, particularly the biconditional ("If and only if"). The findings demonstrated that a significant increase in the understanding of formal implication occurs between Grades 3 and 5, and again between Grade 8 and college level.

The results of this study again support the position that formal deductive competence begins to emerge in an incomplete form around 10–12 years of age, and then goes through a consolidation process. Another important finding of this study is that the primary improvement that occurs between Grade 8 and the college level is in the ability to distinguish the conditional from the biconditional. Because both the conditional and biconditional are formal deductive relationships, it can be speculated that the period beginning at approximately Grade 8 marks the time during which novel interpretative procedures are acquired to adequately interpret and implement the deductive competence. It may be the case, as with means-ends relationships generally, that the emergence of a novel competence initially uses old procedures, and subsequently, new procedures are acquired to meet the demands of the new competence.

When the findings of these latter two studies are considered together, a pattern begins to emerge, suggesting that the period between approximately 10 and 14 years is the time of achievement and consolidation of formal competence, and the period between approximately 14 and 18 years is the time during which novel procedures, adequate to the novel competence, are developed. This schema would also account for why the contradiction training paradigm, employed in earlier research, was unable to detect the availability of competence prior to Grade 12. This paradigm was designed to introduce a formal contradiction that would lead the person from one formal interpretation of the conditional (the biconditional), to another formal interpretation (the conditional). However, distinguishing among such formal interpretations is exactly the interpretative procedural skill that may develop only in the later adolescent years. Thus, the contradiction training paradigm may be evaluating a later developing procedural skill. Once this skill is operating (i.e., by Grade 12) it can access competence, but not before.

Following from the difficulty in detecting deductive competence in early adolescence, we began another series of studies designed to again focus on the issue of developmental availability. After examining several deductive tasks, pilot work led us to a modification of the Wason (1983) selection task. This task presents the participant with a conditional rule (e.g., "If a person is driving a motor vehicle, then the person must be over 16 years of age"). Four cards are also presented. The participant is told that each card has information on one side about whether a person is driving, and on the other side about the age of the person. The problem is to select those cards, and only those cards, that would necessarily have to be turned over to determine if the rule is being broken (i.e., false).

The four card surfaces in view correspond to (a) the affirmation of the antecedent (p) of the rule, (i.e., A person driving); (b) the denial of the antecedent (Not-p), (i.e., A person not driving); (c) the affirmation of the consequent (q), (i.e., A person 18 years of age); and (d) the denial of the consequent) (not-q), (i.e., A person 14 years of age). The correct deductive choices for the falsification of the rule consist of selection of the p card, and the not-q card. The reason for this is that it is these, and only these cards, that could possibly yield the "p and not-q" instance that is required for deductive certainty. That is, the card "A person driving" (p), might yield "A person 14 years of age" (not-q) on the other side, thus giving a necessary falsification of the rule. Similarly, the card "A person 14 years of age," might yield "A person driving" on the other side, again showing the necessary falsification instance.

The selection task is clearly a deductive reasoning task, and one that requires coordination among the permissible and impermissible instances that define implication. Although it focuses on the certainty of the Modus Tollens inference it involves the recognition and coordination of the other inference forms as well. Thus, from a formal perspective, it is well suited for evaluating the systemic availability of deductive competence. Because the rules can be varied in terms of semantic content, the selection task also presents the opportunity to explore procedures that access and implement competence.

Our first set of studies using the selection task (Overton, Ward, Noveck, Black, & O'Brien, 1987) examined the development of deductive availability and the role of semantic content in accessing and implementing this competence. In Experiment 1, participants at Grades 8, 10, and 12 were tested on several familiar content, and several abstract content, selection problems. In Experiment 2, participants at Grades 4, 8, and 12 were tested on the familiar problems used in Experiment 1. In Experiment 3, participants in Grades 4, 6, and 8 were tested on new familiar content problems, familiar content problems with conditional clauses reversed, a meaningful but unfamiliar problem, and an abstract problem.

The findings of these studies were strongly supportive of the developmental competence-procedure model that has been described. First, at all levels, participants performed poorly when abstract problem content (e.g., "If there is a vowel on one side of the card, then there is an even number on the other side.") was used. This is consistent with Wason's (1983) suggestion, that abstract content presents the individual with an overload of information that cannot adequately be represented as a coherent whole. That is, abstract content fails to engage an adequate representational procedure and, thus, does not generally access competence, even when deductive competence is available.

An improvement in performance found for familiar and, to a lesser extent, meaningful but nonfamiliar semantic content, is understood by considering schemata (see Mandler, 1983) as a basic procedure for representational integration. According to this explanation, familiar content produces the greatest facilitation because it most readily evokes world-knowledge schemata. These schemata operate as frames or integrating devices and, thus, permit ready access to and implementation of, available competence. Meaningful but nonfamiliar material is indirectly related to world-knowledge schemata. Hence, it is less adequately integrated and less facilitative.

Abstract content fails to invoke any integrating mechanism. This explanation is also consistent with the lack of any transfer effects from familiar content to abstract content investigated in Experiment 1.

Although the nature of semantic content is an important factor with respect to the access and implementation of competence, the findings supported the position that semantic content cannot, in itself, explain performance. Poor performance in Grades 4 and 6 on even highly familiar problems; variable adequacy across conditions at Grade 8; and the consistently adequate performance at Grades 10 and 12 all suggest the developmental view that formal deductive competence becomes available in adolescence. This position was given further tentative support by findings of a developmental improvement between Grades 8 and 12 on even the abstract problem (Experiment 1) and a logically systematic responding at Grade 8 to problems that had their clauses reversed from the usual semantic order (Experiment 3).

Following from this set of selection task studies, we continued to examine the procedural role of familiarity in relationship to the developmental availability of deductive competence. In the next investigation (Ward & Overton, 1990), however, familiarity was defined in terms of the *relevance* relationship between antecedent and consequence clauses of the conditional rule. Relevance is a logical concept that refers to some identifiable meaningful relationship between the clauses. Based on ratings obtained from children at Grade 5, a group of high relevant (e.g., "If a person is driving a motor vehicle, then the person is over 16 years of age"), and a group of low relevant (e.g., "If a person is driving a motor vehicle, then the person is a school teacher") conditional rules were formulated and placed into a selection task context. Participants at Grades 6, 9, and 12 were tested on these selection task problems.

It was predicted that a high propositional relevance would operate as a facilitative procedure only after deductive competence became available in adolescence. This prediction was supported. At Grade 6, logical solutions were infrequent regardless of the relevance of the rule content. At Grades 9 and 12, low relevant content continued to result in poor performance. However, performance improved significantly between Grades 9 and 12 when the content of the conditional rule involved a high degree of relevance between antecedent and consequent clause. This again suggests that prior to adolescence, deductive competence is not systematically available, and familiarity of semantic content can be considered facilitative, but it cannot explain deductive reasoning itself.

The most interesting developmental finding of this study is that the performance found at each age level for the high relevant groups very closely match the performance levels found for the familiar content problems in Experiments

1 and 2 of the earlier investigation. This consistency occurred despite the fact that the several studies involved different experimenters, different methods, and different problem content.

There are a number of ways to measure deductive success. However, consistency of completely correct deductive solutions across varying content is the most meaningful theoretical measure of the availability of deductive competence. Using the criterion of a minimum of 60% of the problems solved with a correct deductive solutions, the following emerges as the percent of individuals at each Grade level who evidence available deductive competence: Grade 4 = 14% (Experiment 2); Grade 6 = 24% (present study); Grade 8 = 42% (Experiment 2), 48% (Experiment 1); Grade 9 = 75% (Experiment 2), 80% (present study), 86% (Experiment 1). Similar results are found when scoring is computed simply in terms of number of correct solutions across all problems.

The issue of the role of familiar semantic content was pursued and expanded in a later study (Ward, Byrnes, & Overton, in press). Late adolescents were tested with selection task conditional sentences that crossed familiarity and entailment. *Entailment* refers to the case where there is a necessary rather than a contingent relationship between the antecedent and consequent clause of a conditional. Thus, a conditional statement constitutes an entailment if and only if given the statement "if p then q," it is impossible to have a situation in which, p and not-q co-occur. For example, the sentence "If it's a dog then it's a mammal" asserts an entailment relationship because it is impossible to find the case of a non-mammal dog. It was predicted that entailment as a structural feature would be a stronger determinant of correct reasoning performance than familiarity, and this prediction was supported.

The consistent, but indirect, evidence for developmental changes in the availability of deductive competence across the several studies, and the similarity of scores at each age level across the several studies, led us to undertake a longitudinal investigation to further examine the development of deductive competence (Reene & Overton, 1989). Participants at Grades 6 and 8 were tested on the high relevant selection problems from the Ward and Overton study. They were then retested a year later at Grades 7 and 9. Grades 6 and 7 did not differ in performance, whereas Grade 9 showed a significant improvement over Grade 8. Using the consistency of solution criterion described above, the percent of individuals at each grade level who evidenced available deductive competence was: Cohort 1: Grade 6 = 17%; Grade 7 = 38%; Cohort 2: Grade 8 = 38%; Grade 9 = 60%. These longitudinal findings are highly consistent with the earlier cross-sectional research. Testing on the third year of this project has been completed and the results continue to support the cross sectional studies. For Cohort 1, the Grade 7 performance level of 38% was followed by a Grade 8 performance level of 53%. For Cohort 2, the Grade 9 performance of 60% was followed by a Grade 10 performance of 67%.

In addition to scoring the selection task according to number of correct solutions, and according to consistency of correct solutions, it is possible to examine error response patterns. For example, selection of the p card and the q card yields the p,q error pattern. This pattern, which represents a matching of the selection cards to the antecedent and consequence clauses of the rule, has generally been interpreted as a failure of logical understanding. In the described studies, as would be expected, this pattern decreases directly in relation to increasing age. Another error pattern, which presents greater developmental interest is the p,q,not-q pattern. Wason and Johnson-Laird (1972) suggested that this pattern represents partial insight into the correct logical solution. Here the individual selects the correct p card, and the correct not-q card, but contaminates the solution by continuing to choose the matching q card.

Pollack, Ward, and Overton (1988) explored the hypothesis that the p,q,not-q error pattern may mark a developmental transition in the progression toward a systemic available deductive competence. In reviewing the error data from the Overton et al. (1987) study, we found that in two of the three experiments there was an inverted-U-shaped relationship between grade (4, 8, and 12) and selection of the p,q,not-q pattern. Grade 8 constituted the maximum point of the curve. This finding, along with Wason and Johnson-Laird's interpretative suggestion led to the further exploration of this pattern for individuals at Grades 4, 5, 6, 8, 9, 12, and college level. The high-relevant selection task problems from the Ward and Overton (1990) study were used in this investigation. The results supported the conclusion that there is a curvilinear relationship between grade and the p,q,not-q pattern. Grade 8 constituted the maximum point of the curve, whereas Grades 4 and college level constituted the minimum points.

This support for the hypothesis of a transition to a deductive competence led to a follow-up investigation that employed data from the first 2 years of the longitudinal study mentioned earlier. In this follow-up (Reene, Pollack, & Overton, 1989), the age-related curvilinear relationship in the production of p,q,not-q pattern was again found. The seventh and eighth grades constituted the maximum points of the curve, whereas the sixth and ninth grades constituted the minimum points.

When the findings from the last two studies are considered in the light of the Byrnes and Overton (1986, 1988) investigations, additional weight is added to the suggestion that sometime around 14 years of age (Grade 8) a transition occurs. This transition may mark the end of the consolidation of formal competence, and the beginning of the development of novel procedures designed to access this competence.

CONCLUSION

The basic thesis of this chapter has been that an adequate scientific theory of the nature, origin, and development of any human capacity requires an integrated set of explanatory concepts. Competence models offer explanation for the universal features of understanding at different levels of development. Procedure models offer explanations for how competence is accessed and implemented in real time at various levels of development. The research program that has been described represents a continuing effort designed to explore, examine, and elaborate the empirical implications of this framework in the domain of the development of deductive reasoning.

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