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Naturalistic Cognition: A Research Paradigm for Human-Centered Design

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Abstract

Naturalistic thinking and knowing, the tacit, experiential, and intuitive reasoning of everyday interaction, have long been regarded as inferior to formal reason and labeled primitive, fallible, subjective, superstitious, and in some cases ineffable. But, naturalistic thinking is more rational and definable than it appears. It is also relevant to design. Inquiry into the mechanisms of naturalistic thinking and knowledge can bring its resources into focus and enable designers to create better, human-centered designs for use in real-world settings. This article makes a case for the explicit, formal study of implicit, naturalistic thinking within the fields of design. It develops a framework for defining and studying naturalistic thinking and knowledge, for integrating them into design research and practice, and for developing a more integrated, consistent theory of knowledge in design. It will (a) outline historical definitions of knowledge, attitudes toward formal and naturalistic thinking, and the difficulties presented by the co-presence of formal and naturalistic thinking in design, (b) define and contrast formal and naturalistic thinking as two distinct human cognitive systems, (c) demonstrate the importance of naturalistic cognition in formal thinking and real-world judgment, (d) demonstrate methods for researching naturalistic thinking that can be of use in design, and (e) briefly discuss the impact on design theory of admitting naturalistic thinking as valid, systematic, and knowable.

Keywords: formal reason; naturalistic cognition; phenomenological knowing; situated cognition; human-centered design; vicarious function; Brunswik's lens model

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1. Historical Background

Western philosophy and culture have a long history of valuing explicit, formal reason, typified by science and discounting naturalistic thinking. Formal reason represents the emergence of human knowledge and wisdom over base instinct and superstition. In the early nineteenth century, August Comte proposed the application of formal, scientific constructs and methods across human domains. Comte's positivism is, even now, in the postmodern period, taken for granted as normative, for example, in the increasing importance of evidence-based practice in fields ranging from medicine (Cochrane, 1972; Evidence-Based Medicine Working Group, 1992), to education (Slavin, 2002), to art therapy (Gilroy, 2006), and law enforcement (Sherman, 1998). Formal methods are so equated with rigor and validity that they are regularly used without theoretical frameworks, often to generate theories bottom-up rather than to test them. "The branches of empirical science that have the least substantial theoretical developments often have the most sophisticated methods of evaluating evidence" (Suppes, 1962, p. 260). Thus, formal methods become fetish, giving the appearance of rigor, though without a solid theory of the thing being tested, one cannot know what is actually being measured. Theory built out of such research is ad hoc congeries and reifies prejudices. Experimental psychology has this problem, conspicuously in its use of contrived laboratory experiments, its "free floating empirical foundation" (Kirlik & Storkerson, 2010, p. 33), and statistical methods that cannot stand scrutiny (Cohen, 1990, 1994). Design's ready use of methods and interpretations from other fields carries the same liability.

I need to stop briefly to clarify the language used in this article. The article is built around the dichotomy between deliberate, formal, thinking and knowledge, and the implicit, naturalistic, ecological cognition of everyday existence. Various kinds of naturalistic thinking and knowing have been given many different labels such as "non-conscious," "unconscious," "implicit," "experiential," and "embodied." Using any one term characterizes this broad phenomenon as one of its characteristics, neglecting the others. Wherever possible, I use the terms, *natural* or *naturalistic*, and *ecological*, because they are most relevant to the focus of this article. *Natural* and *naturalistic* distinguish the natural world from formal systems and point to the limitations of formal systems in capturing natural world functioning. The term *ecological* refers to the ontology and epistemology of the natural world as it is experienced: that all knowledge starts with "things that are now the material of experience" (Dewey, 1925, p. 12), and it makes sense when it can be related back to the material of experience. It is also important to clarify the term *abstract*. It is commonly thought of as meaning divorced from reality, but that is not necessarily the case. What abstract means is universal: independent of any specific context. An abstraction can be divorced from reality if it is not or cannot be related back to the material of experience, and that is a bane of intellectualism (Dewey, 1925, p. 28).

Design highlights two contradictions created by the accepted view of knowledge as formal knowledge. First, formal rule structured thinking is unable to do many things that people do, like understanding everyday language and forming judgments: "The structure and representation of knowledge required for intelligent action is one of the most problematic subjects confronting cognitive science" (Smith & Marshall, 1998, p. 333).

Second, the natural world is not avoidable. Within philosophy of science, Hillary Putnam (1962, pp. 240-251) demonstrated how abstract concepts retain naturalistic content, even in science. George Lakoff and Mark Johnson (Johnson, 1987, 2007; Lakoff, 1987; Lakoff & Johnson, 1980, 1999) demonstrate the importance of naturalistic content in forming abstract concepts and theories. Patrick Suppes (1962, p. 259) demonstrated that even in scientific experiments, applying abstract theories to empirical testing requires the mediation of multiple models to simplify and translate formal principles into specific concrete operationalizations (e.g., model of the theory, model of the situation or experiment, model of outcome or data, model of unavoidable stray environmental variables that may affect outcomes or data). The theory-model relationship should be familiar to designers as the gap between the goals and criteria a design should fulfill and the determinate form of the design itself, which is at best an approximate fulfillment of any criteria: incomplete, with its own added attributes and its limitations, but sufficing under particular circumstances. Designs are natural world models of goals and criteria.

The idea of "knowledge" is problematic in design, because design is concerned simultaneously with formal and naturalistic thinking in both users and designers: so much so that a significant part of its applied knowledge is naturalistic. On the level of design theory, thoughtful designers debate whether design should aspire to the formal knowledge of science, or the practical knowledge of artisanship (Cross, 2007), or if it should follow a technocratic model (Owen, 1990) and so forth. There is also debate over whether tacit knowledge should be placed alongside formal knowledge (Rust, 2007) and whether artifacts themselves can be carriers of communicable tacit knowledge/content (Candlin, 2000), and in some subfields of design education, formal knowledge and research are pedagogically and institutionally disfavored (Storkerson, 2008, 2010).

Design is not alone in its contradictions; those contradictions reflect how the nature of knowledge has been changing in knowledge-based societies. As knowledge production has increased, and particularly as research is being shaped by social and economic factors (David, 1995, cited in Nowotny, Scott, & Gibbons, 2001, p. 4), the distinction between the context-free formal knowledge typified by science and situation-based, practical knowledge has been blurred, to produce "contextualized knowledge."

> In reductionist science, still the mode to which many scientists aspire, it is necessary to establish clear boundaries that frame the scientific arena, and distinguish science from non-science. Mode-2 [contextualized] knowledge production, in contrast, takes place within and between open and shifting boundaries. It consists of the reconfiguration of knowledge and people. It is transgressively bounded because . . . a new kind of integration with the context is made possible. . . . "People have been allowed a place in our knowledge" and thus, "the context (can and does) speak back." (Nowotny, Scott, & Gibbons, 2001, pp. 19-20)

Contextualized knowledge, such as design, inverts a historic relationship. Science re-forms the natural world according to its formal concepts. In contextualized knowledge, the natural world re-forms formal knowledge according to its pragmatic goals and social order. Pragmatics is the heart of design.

2. Two Cognitive Systems

So, what are formal and naturalistic thinking and knowledge and how do they differ? Can naturalistic thinking be counted as knowledge at all? In this paper, I consider formal thinking as it is typically understood and practiced by non-philosophers (Johnson-Laird, 2006). Western formal thinking has roots in Aristotelian and stoic models of valid and sound predicate logic (Lear, 1980). It has been heavily influenced by experimental science and technology as they have pervaded social life and education. Formal thinking is deliberative analysis using observations, concepts, and principles, in which empirical objects are redefined as sets of attributes (billiard ball as a sphere with a certain mass and elasticity), which interact according to a set of rules called a theory. It uses complete (closed) systems, in which elements are unambiguously specified. Questions, such as "What causes heart attacks?" are not addressed directly, but through testing hypotheses (abductions), such as "Let's see if smoking causes heart attacks." Thus, formal thinking cannot create models or solutions, only expose them. "Solving" an equation removes extraneous elements and rearranges what is left to reveal a solution that was there all the time. Formal thinking has its creativity, too. It can draw out unanticipated implications that produce gestalt changing outcomes such as the discovery of imaginary numbers.

2.1. Naturalistic Cognition

This article lumps various phenomena such as expertise and tacit knowledge into single category, begging the question of whether they actually belong together. There are distinct reasons for doing so. They are part of a discrete cognitive system--*naturalistic cognition*. It is a cognitive system in that it combines thinking, knowing, perceiving, remembering, and acting as interconnected parts of a whole rather than as separate faculties. It goes unrecognized because it is implicit: hidden from conscious awareness. Formal thinking receives natural cognition's outputs but is largely unaware of its existence (McGilchrist, 2009). Naturalistic cognition is the process through which a conscious body connects with its environment. It constructs perception so well that the world as perceived is taken to be the world that is. Naturalistic cognition is holistic, mimetic, and *schema* based rather than discretely focused, conceptual, and analytic. It combines perception, feeling, and action, like recoiling from touching a hot stove. Naturalistic cognition covers what appears to be a grab bag of phenomena:

(a) Tacit knowledge is knowledge or skill that cannot be articulated (Polanyi, 1967; Reber, 1993; Reber & Lewis, 1977). It is sometimes described as knowing but not knowing what one knows, or knowing the right answer without knowing how it was arrived at. It is the dominant mode of learning in graphic and communication design.

(b) Experience-based expertise is closely related to tacit knowledge. It often operates on top of a base of explicit knowledge as real-world experience that relates formal knowledge to specific situations as, for example, a skilled surgeon's judgment.

(c) Naturalistic thinking, judgment, and decision making represent thinking and knowledge outside of explicit formal knowledge, for example, use of natural language, or judgment under uncertainty (Beach & Lipshitz, 1993; Hogarth & Kunreuther, 1995; Lipschitz & Strauss, 1997).

(d) Perceptual or "embodied cognition," is based on everyday physical experience such as up or down, pushing, hunger and eating, and the associated body states of tension, relaxation, motion, completion, and so forth (Johnson, 2007, pp. 135-145).

Perceptual cognition determines the characteristics of experience: the organism's internal representations of itself and its environment. One does not perceive sounds as in one's ears, or sights as in one's eyes. In perception, such proximal sensations are translated into spatial and temporal continuities with the three-dimensional objects, sounds, and events at distance (Gibson, 1966, pp. 7-30). Perception's construction of three-dimensional space with solid objects goes largely unrecognized, but it is striking in the blind person who sees using a cane (Merleau-Ponty, 1964, p. 170).

Affect is as integral to naturalistic cognition as it is external to formal thinking. It is so closely related to body and muscle states that emotional states can be induced physically (Stepner & Stack, 1993). Phenomenological knowing, which is the sense of knowing, is a naturalistic reality check indicating that something suspected or deduced is real. Capgras syndrome is suffered by persons who, because of brain injury, lack connections between visual and affective brain centers. They are able to recognize relatives but lack the sense of knowing. They are prone to misidentify relatives as imposters or replicants (Young, 2007). It is a very specific injury that disrupts only visual recognition: familiar voices heard over telephone are identified correctly.

Naturalistic cognition has been reassessed in recent decades, because of the growing interest in tacit learning (Reber & Lewis, 1977), judgment and decision making (Zsambok & Klein, 1997) and problem solving and situated cognition (Kirsh, 2009). The definition of cognition has broadened toward the construct of a hidden or implicit layer (often called unconscious) of cognition.

> [T]here now exists substantial evidence that the unconscious is not identifiably less flexible, complex, controlling, deliberative, or action-oriented than is its [conscious] counterpart. . . . Research has demonstrated the existence of several independent unconscious behavioral guidance systems: perceptual, evaluative, and motivational. (Bargh & Morsella, 2008, p. 73)

Jonathan Evans (2007) documented many "dual process" models of "conscious" (i.e., deliberate or explicit) and "unconscious" (i.e., implicit, naturalistic) cognition, proposed between 1983 and 2004 (e.g., Chen, & Chaiken, 1999; Chaiken & Trope, 1999; Epstein, 1994; Epstein & Pacini, 1999; Fodor, 1983, 2001; Sloman, 1996). Table 1 below selects data from the larger table compiled by Evans.

Table 1. *Dual Process Models of Cognition (after Evans, 2007)*

System 1 (Naturalistic)	**System 2 (Explicate)**
Consciousness	
Unconscious	Conscious
Implicit	Explicit
Automatic	Controlled
Low effort	High effort
Rapid	Slow
High capacity	Low capacity
Default process	Inhibitory
Holistic, perceptual	Analytic, reflective
Functional Characteristics	
Associative	Rule based
Contextualized	Abstract
Pragmatic	Logical
Parallel	Sequential
Stereotypical (based on repeating patterns)	Egalitarian
Individual Differences	
Universal	Heritable
Independent of general intelligence	Linked to general intelligence
Independent of working memory	Limited by working memory

"In other words, System 2 [deliberative thinking] is a form of thinking under intentional level control, supported by unconscious processes in System 1 [naturalistic cognition] that deliver percepts, memories, and so on" (Evans, 2007, p. 258). Table 1 shows the emerging general model of naturalistic cognition as concrete, immediate, and connected to the body, bodily experience, and affect. It supports the flow of interaction, while deliberative thinking is abstract, analytic, dispassionate, and inhibitory, which is to say, it stops the flow of action. The naturalistic system is powerful. It processes and supports the flow of interaction in real time, and its function is not related to general measures of intelligence, such as IQ.

Neural models relate formal and naturalistic cognition to brain topology: the naturalistic "silent" right hemisphere, the deliberative and formal left hemisphere and the corpus callosum, which regulates communication between them. Within a neural model, naturalistic knowing is intuitive, because the communications between consciousness and implicit processes are strictly limited. Introspection and self-reports, such as accounts of why one did something, can be complete fabrications. They are plausible logical reconstructions of processes that are not accessible, "telling more than we can know" (Nisbet & Wilson, 1977, p. 231).

Deliberative, formal thinking is dependent on implicit cognition. The literature on brain damage includes observations of persons whose right hemisphere (locus of implicit cognition) is compromised, leaving the left hemisphere (locus of deliberative cognition) alone. When such persons are given a well formed but factually false proposition such as, *All monkeys climb trees; the porcupine is a monkey; so the porcupine climbs trees*, they agree that porcupines climb trees. When they are informed or reminded that porcupines are not monkeys, they are unable to change their judgment (McGilchrist 2009, pp. 192-193). The formal logic based, "computational" model of brain function as computer-like symbol manipulator (Pylyshyn, 1973) has been criticized (e.g., Kosslyn & Pomerantz, 1977) for its inability to connect the brain to the natural world: the "brain in a vat" problem (Putnam, 1981, pp. 1-21). The case above is one of a number indicating that the left hemisphere by itself really can act like a brain in a vat. Other effects of isolating left hemisphere thinking include pathological overconfidence in one's judgments (no reality check), inability to appropriately connect need to action, and lack of empathic connection to others, leading to psychopathy (McGilchrist, 2009, p. 146).

While deliberative, formal thinking is propositional and logical, naturalistic cognition is mimetic, built from the repetitive patterns of experience (Johnson, 2007, pp. 111-134). The infant's life is full of repetitive patterns in its environment, its behaviors and its interactions, as infant and caregiver mirror each other. Repetitions build patterns or schemas of objects, spatial configurations, events, and situations, including one's own behaviors (Kurtoglu & Stahovich, 2002, Brewer & Nakamura, 1984), which are basic building blocks of naturalistic cognition. Schemas are experience oriented rather than abstraction driven. They need not be computed but can be cued in memory (Alba & Hasher, 1983), as a fragment of fabric sticking up behind a desk cues perception of a chair, or the cracking sound of a branch cues its immanent fall and the impulse to move out of its way. Since schemas are based on recurrence they may individually be fallible, but when many are used in quasi-redundant combinations, they can be quite robust. Perceptual illusions are carefully contrived and often operate by limiting the information available.

The mimetic, pattern sensitivity of naturalistic cognition enables it to operate where formal thinking cannot, by using repetitions to give form to open and ill-formed contexts, particularly as structured by the organism's physical *affordances*, behaviors, and goals. Like formal thinking, naturalistic cognition models its environment as causal and predictable, but natural environments are uncertain, so naturalistic cognition stresses quick, likely to succeed judgments and actions, with ongoing monitoring and adaptation, rather than complex investigation and proof of correctness (Gigerenzer, 1999).

Naturalistic cognition is found in the intuitive understanding of addition (I + II = III), spatial relations, geometry, movement, and physical characteristics. Gärdenfors (2004, pp. 15-21) demonstrates correspondences of intuitive logic to classical geometry. Such implicit knowledge is intuitive and immediate, that is, without apparent reasoning. It is also dependent on memory and recognition, thus on the mnemonics of semantic and sensory patterns and features (Rubin, 1995a, 1995b). It is often expressed and remembered in the naturalistic form of narratives: "People will nearly always make sense of their experiences by constructing them in story form, and sometimes (but not always) they will proceed from these stories to infer or deduce generalizations" (Baumeister & Newman, 1995, p. 98).

Naturalistic cognition is not able to perform complex chains of calculations like solving equations, but it is able to compare large numbers of data rapidly, in parallel, to detect correspondences and discern coherence, or to play out possible scenarios. Because it is not theoretical or systematic, naturalistic knowledge is holistic (i.e., non-analytical); recognizing someone is intuitive, while conscious awareness of exactly what features are being recognized can be an entirely different matter. It is also analogical, in that new objects or situations can be processed according to their schematic resemblances to earlier ones.

3. Naturalism in Formal Knowledge

Formal knowledge codifies that which has been conceived naturalistically. Classical geometry owes much to folding and cutting (Stjernfelt, 2007, pp. 89-116). Elementary school students can be taught probability theory graphically. In Figure 1 below, a diagram decodes the mystery of central tendency in probability. One can see that even though on any toss a head and a tail are equally likely, three tosses in a row of heads or of tails are less likely than mixes of heads and tails. The mathematical formula expresses and summarizes the natural world model from which it is derived.

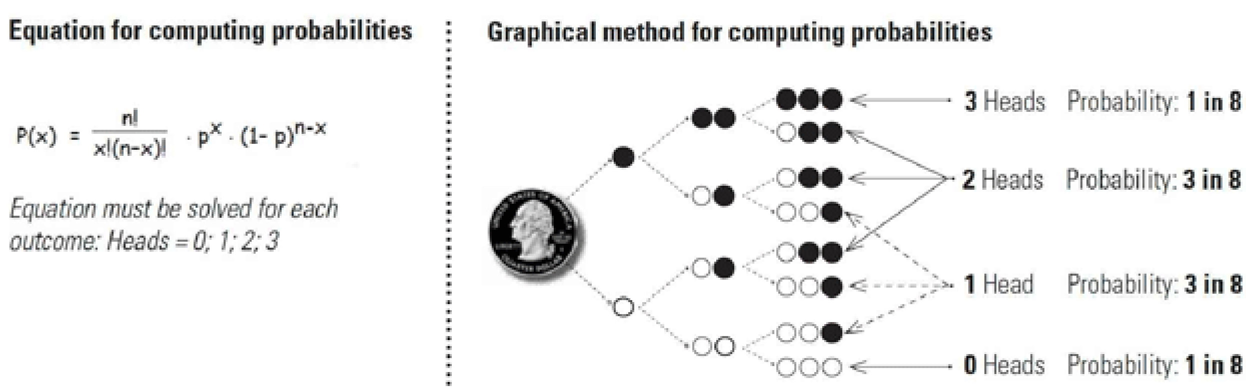

Figure 1. Tree diagram of binomial probability distribution.

It is fair to say that deliberative, formal thinking is not something that human beings do naturally or easily. Suppes' (1962) argument that people need naturalistic models to make use of abstract concepts and theories has been well born out. Johnson-Laird (1980, 1981) proposed the idea of the mental model as a naturalistic operationalization that can be used to project how something abstract works. Models have metaphorical and metonymic relations to their abstract objects, that is, the whole of the theory is represented by a naturalistic model that is analogous to some part of it.

Mental models are not merely figurative paths to constructing understanding of those objects; they are taken as descriptive. Their natural world entailments are transferred. Johnson-Laird stressed the model as an implicit plan for approaching a problem and the difficulties that it represents. For example, people will solve a proposition in the order in which it is given and miss implications that would be obvious if one examined the it in a different way. He also stressed the limitations of the models themselves. For instance let us say there are five people. The second is on the first's right, the third is on the second's right, and so forth. The logic of the proposition leads to the conclusion that the fifth is on the first's right, but what if they are in a circle? (Johnson-Laird, 1980, p.87). In short, mental models encode unrecognized assumptions (people in a line), so they break in ways that cannot be systematically predicted and may escape detection.

Lakoff and Johnson (Johnson, 1987, 2007; Lakoff, 1987; Lakoff & Johnson, 1980, 1999) use the term *metaphor*. Their metaphors are equivalent to Johnson-Laird's models, because their natural world entailments are also transferred to their objects, and for that reason they affect how their objects can be thought about. Johnson compares the naturalizing metaphors in arithmetic of collections of objects to movement on a path. For example, three balls can be removed from a sac of five leaving two, but removing seven is not possible, so negative numbers make no sense here. But, negative numbers can be translated into movement along a path. If the next town is five miles down the path and one walks three miles down the path, the next town is two miles ahead. If one walks seven miles down the path the town is two miles back. "Consequently, these two metaphors are not merely alternative ways of conceptualizing the same arithmetical process. Their ontologies, the entities they posit, and the operations they support are not identical" (Johnson, 2007, p. 183). When models are used to understand abstractions, it is actually the models that are understood.

It is also fair to say that formal thinking is not something that human beings do well. People actually accomplish formal thinking tasks by naturalistic means. Human limitations of serial processing and memory quickly force the use of external aids. As Charles Wiener was interviewing physicist Richard Feynman for a biography, he referred to Feynman's work notes as records of his thinking. Feynman retorted, "No, it's not a record, not really. It's working. You have to work on paper, and this is the paper. Okay?" (Gleick, 1993, p. 409). The physicist solves equations by spatially manipulating an equation's symbols on paper. That manipulation is based on a spatial calculation system. The explicit rules for transposing elements of an equation are like the moves of chess pieces (Brockmole, Hambrick, Windisch, & Henderson, 2008). Solving the equation is based on a repertory of legal moves to achieve a spatial configuration that reveals "the answer" as a statement of equality. The procedure is entirely independent of what the terms relate to in the world. Where formulae themselves become complex, solving them can be like chess: using experience-based strategies for achieving the right configuration. These ways of naturalizing formal thinking put the idea of formal thinking as a superior mental process into question and demonstrate how formal thinking is entangled with naturalist thinking.

3.1. Naturalistic Cognition in the Natural World

Naturalistic cognition is a continuous, real-time process of making judgments, decisions, and actions: figuring out what is going on, and acting to adapt to it or change it. Expertise in judgment and decision making is a good place to examine naturalistic cognition. In Dreyfus's five-stage model of expertise (Table 2), explicit, formal knowledge is the first stage. Instruction on how to use steering, clutch, and so forth provides the explicit knowledge that enables the student to start the process of experiential learning by actually driving. Competence, proficiency, and finally expertise result from acquiring tacit, experiential knowledge and recognition of situations, to automate those levels and strategically focus on the highest level of thinking: the problematic or unpredicted.

With enough experience with a variety of situations, all seen from the same perspective but requiring different actual decisions, the proficient performer gradually decomposes this class of situations into subclasses, each of which share the same decision, single action or tactic. This enables the immediate intuitive response to each situation which is characteristic of expertise. (Dreyfus, 1997, p. 22)

Table 2. *Dreyfus's Five Levels of Expertise (Dreyfus, 1999)*

Level of Expertise	**Characteristics**
Novice	Task decomposed by instructor into abstract context-free features (procedures for operating a car). Attention to "rules" relating action to features (how to implement the procedures).
Advanced Beginner	Introduction and instruction regarding situational aspects (engine sound). Introduction of non-situational aspects (indicated speed for shifting).
Competent	Increased situational awareness. Need to develop a strategy to allocate attention to what is important in the given situation. Assimilation of experience and ability to function when multiple decisions are required in real time (how much to slow down for curve ahead given road conditions, etc.) and when results are unexpected (a skid).
Proficient	Intuitive behavior (assimilation of prior levels into unconscious functioning). Intuitive discrimination of situations and responses to them. Sense of "obviousness."
Expert	Knows what needs to be done and how to do it Subtlety in discrimination of situations. "Intuitive, immediate response to each situation."

Naturalistic thinking serves a different purpose from formal thinking. It interprets situations and resolves uncertainties. Lipshitz and Strauss (1997, p. 151), for example, distinguish three basic types of uncertainty: (a) uncertainty of one's understanding of the situation (one's theory), (b) inadequate or equivocal information, and (c) diverging or conflicting alternative actions. Uncertainties pervade everyday judgments (e.g., while driving: *Is that car going to stop? If not, should I?*). Thus, decision making in the natural world often requires that uncertainties be resolved into a "best guess" judgment, requiring experiential knowledge and thinking. The solutions may not be the unique "correct" ones (if correct ones could even be determined), but they strive to be the best, actionable choices available under the circumstances, to achieve goals, avoid disasters or, at least, to stay in the game. Experts provide concrete, experience-based information to assess the situation, play out strategies, and structure the decision space.

Naturalistic knowledge carries with it metaknowledge, such as when and where something was learned, from whom, the reliability and biases of the source, the situational context, and so forth. This contextualization, which is uncharacteristic of formal knowledge, is often encapsulated in narratives. Roger Schank (1990) documented how people react to queries differently from machines. Given a patient's symptoms, an expert system, such as the doctor's Personal Digital Assistant (PDA), will calculate and return the likely diagnoses, treatments, and other advisements according to evidence-based practice. A colleague is more likely to tell a story that will include diagnostic and treatment pitfalls, patient variations, and other contextualizing metaknowledge based on experience. In the field of human factors, which specializes in human-technology interaction, the incorporation of metadata is used to address the reliability of information. For example, the metadata around a thermometer reading could include its accuracy, its reading speed and overshoot, its condition, its location, and so forth. All of these can be used to recalibrate one's interpretation of a reading or determine its reliability under the specific conditions (Zuk & Carpendale, 2006). There is also increasing interest in and research on schema-based naturalistic decision aids that come closer to Schank's model of human consultation (Smith & Marshall, 1997).

4. Doing Empirical Research: Egon Brunswik's Ecological Approach to Human Judgment

This paper has considered formal thinking and naturalistic cognition from an empirical standpoint rather than a speculative one. It has two practical goals: to enable naturalistic cognition to be an object of knowledge and to provide frameworks for studying both formal and naturalistic thinking. Egon Brunswik was a psychologist whose work focused on perception and interaction. His "lens model" and his theory of representative experiment design are both direct entailments of his analysis of functional human-environment interaction.

Brunswik's framework for studying naturalistic knowledge (judgment) and action that is well established, particularly in the field of human factors. Brunswik argued that the ecological interaction of the organism, human or animal, with his or her environment is the objective level of functioning: at which one achieves or fails to achieve goals, survives or perishes. He developed a theoretical and methodological approach that includes naturalistic cognitive processes and supports quantitative research into the variables underlying judgment and decision making (Goldstein, 2006). Brunswik saw his work as an evolution away from both Gestalt introspection and behaviorist positivism, toward a functional perspective that combines the richness of Gestalt accounts with a rigor comparable to that of behaviorist measurements (Goldstein, 2006, pp. 11-14). Brunswik's approach has a distinctive set of characteristics:

(a) It is centered not on stimulus-response, but on the ecological level of everyday interaction between organism and environment as the appropriate "objective" level of analysis. The relationship between the environment and the organism's perception and behavioral strategies is functional (Tolman & Brunswik, 1935, p. 61). It does not matter what form perception of the cliff takes or what behavior the organism uses to avoid falling of it as long as it does not fall off. Gibson (1966) further developed this approach by describing perception not as the reception of stimuli from the environment, but as the organism's active search for information to inform action.

(b) The organism seeks to act appropriately with the environment and for the furtherance of its goals such as survival and reproduction (Tolman, 1951, p. 13).

(c) The organism builds a model of the environment as cause and effect, but with high variability and uncertainty, which corresponds to the uncertainties of natural environments (Tolman & Brunswik, 1935, p. 45).

(d) The organism does not perceive sensory inputs, but objects and events on the ecological level. Cognitive function utilizes and organizes the "proximal" sensory inputs as signs or cues to form an intentional, coherent perception of the "distal" environment (Tolman & Brunswik, 1935, pp. 67-73).

(e) The organism's perceptual relation to its environment is semiotic. It uses sensory inputs as signs or cues (Brunswik, 1952, p. 22), which it uses to form perception.

(f) The organism forms perceptions using "vicarious function," a concept first used by Hunter (1932). Vicarious functioning is purposive behavior in which multiple sensory inputs are selected, construed, and combined by a higher level cognitive system that creates perception (Brunswik, 1952, pp. 16-20).

Psychological behaviorism, of Thorndike, Watson, and Skinner, intended to remove consciousness and interpretation from psychology (Watson, 1913, p. 177) using a bottom-up approach in which simple reactions combine to form complex ones. Brunswik's roots were in Gestalt psychology, which argued that wholes are not simply built up from parts, but that the parts are used in the active, intentional processes that seek to define wholes: "There are wholes, the behaviour of which is not determined by that of their individual elements, but where the part-processes are themselves determined by the intrinsic nature of the whole" (Wertheimer, 1924). Brunswik extended Gestalt theory beyond perception to interaction between organism and environment, including the organism's representations of its environment and itself, and its actions. Brunswik's perceptual model centers on the relationship between proximal sensory information and the distal environment as perceived.

> Adequate adjustment to the world requires accurate perception and effective actions, and these are matters of central distal correspondence: (1) bringing one's (central) perceptions into line with (distal) objects and (2) bringing about (distal) states of affairs that coincide with one's (central) desires. (Goldstein, 2006, p. 12)

Natural environments operate by cause and effect but have limited predictability.

> [C]ausal connections are probably always to some degree *equivocal* (*mehrdeutig*). . . . And it is indeed, we would assert, this very *equivocality* (*Mehrdeutigkeit*) in the causal "representation"-strands in the environment which lend to the psychological activities of organisms many of their most outstanding characteristics. (Tolman & Brunswick, 1935, p. 44, italics in the original)

The answers to equivocality are redundancy and "vicarious function," the combining and cross-checking whatever sensory data are at hand to build a perception and assay behavioral means: "Hunter, concentrates on the implications of . . . [vicarious functioning] upon the flexibility and exchangeability of pathways relative to an end when he elevates 'vicarious functioning' to the role of the defining criterion of the subject matter of psychology" (Brunswik, 1952, p. 17).

Brunswik applied the notion of vicarious function to research methodology as well. Experiments that are representative of human perception and interaction should study persons functioning on an ecological level, vicariously, using multiple cues (Brunswik, 1956). Brunswik used this approach in his work on perceptual size and shape constancy. For example, the optically tiny clock on a bell tower is recognized as a much bigger object than the optically larger alarm clock within arm's reach. This work demonstrated that the proximal sense impressions on the retina, which may change radically, do not determine the object perceived. Instead, the organism uses multiple cues vicariously, for example, "when geometric objects . . . are shown in an indoor setting that furnishes a normal array of distance cues" (Wertheimer, 1924, p. 18). This approach sharply contrasts with the behaviorist method of testing single variables. Dreyfus made Brunswik's point with respect to studies of expertise, that is, that human expertise is based on vicarious function using multiple schemas from experience rather than a compilation of the single variables behaviorists study.

> As you all know, everyday, skilled decision making has been systematically overlooked in laboratory studies that study decision making outside the natural context in which the decision maker has experience-based expertise. Such studies force the subject to behave in nonskillful ways and so enforce the traditional account of deliberation as applying rules to situations defined in terms of context-free features. (Dreyfus, 1997, p. 23)

4.1. The Lens Model

Brunswik crystalized his approach, in his lens model of perception and interaction, focusing on the functional "rapport" between organism and environment: the organism's ability to act in ways apposite to the objects and events of that environment, to achieve its ends. The organism needs to create a representation that maps to those aspects of the environment that are relevant to the organism's interaction and survival. The distal objects of the environment are made available to the organism through a series of mediating sensory cues along with noise and errors: spurious or stray inputs from the environment and stray effects of the cues. The organism's achievement of the perceived continuity of the distal object is effected through purposive "vicarious processing," which flexibly combines multiple inputs as cues to form a coherent interpretation.

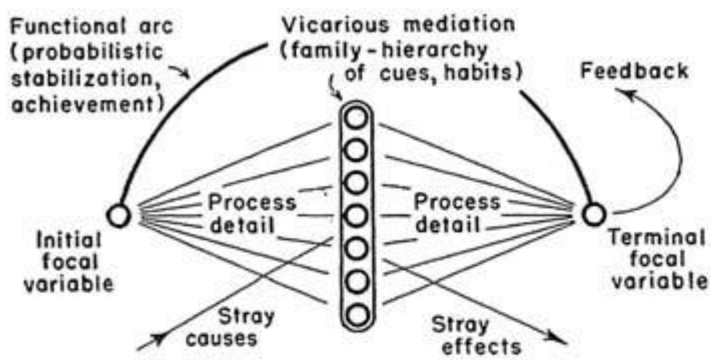

Figure 2. The lens model: composite picture of the functional unit of behavior (from Brunswik, 1952, p. 20, © 1952 University of Chicago Press, reproduced with permission).

Cues can be evaluated across dimensions including whether they are misleading, non-significant, ambiguous, reliable, or where the model is used for behavior, whether behavioral means are good, bad, indifferent, or ambiguous in their efficacy (Tolman & Brunswik, 1935, cited in Hammond & Stewart, 2001, p. 17). Through such qualifiers, vicarious functioning incorporates metaknowledge into the information.

4.2. Application of the Lens Model

The lens model addresses naturalistic cognition and offers ways to systematically analyze how it functions in practice, including the real-life use of formal systems. It provides analytical tools for more systematically integrating experience-based knowledge into design. It is a template that can be scaled, elaborated, and extended in various ways for situations of varying complexity. The following example is presented to show how Brunswik's lens model is being successfully used. Here, it analytically decomposes judgments into cues and vicarious processing.

Stewart and Lusk (1994) adapted and applied the lens model to experiments in judgment formation in weather forecasting. The experimental task was to predict "microbursts," which are localized, rapidly developing weather events that pose serious threats to aviation. Figure 3 shows Stewart and Lusk's elaboration of the lens model.

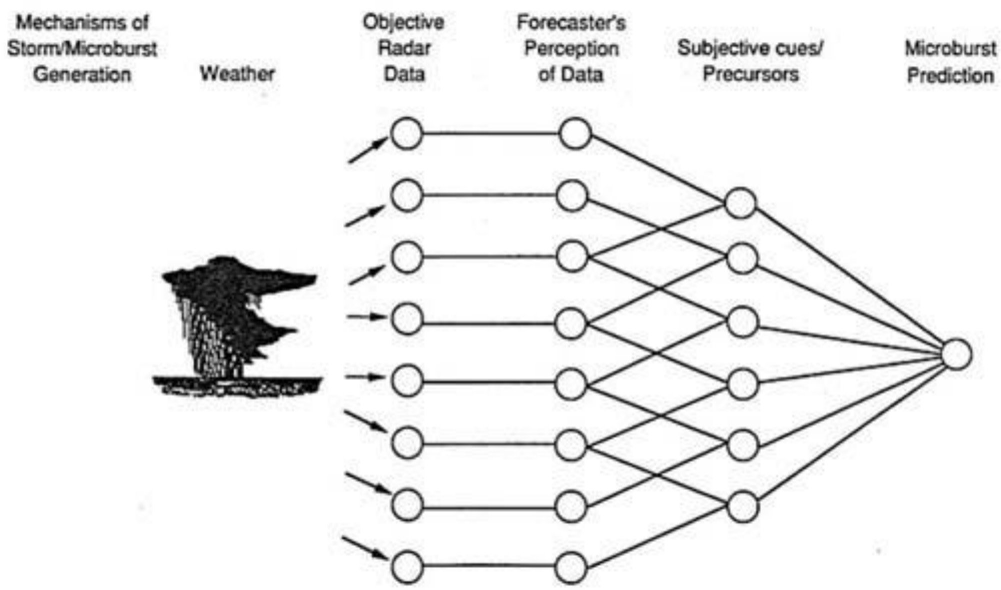

Figure 3. Sequence of phases in microburst forecasting (from Lusk, Stewart, Hammond, & Pons, 1990, p. 628).

Forecasters worked in facilities with informational displays indicating external conditions through measurements. On the basis of those displays, their training, experience, and judgment, forecasters predicted the likelihood of microbursts occurring within 15 minutes near individual airports. The stages of forecasting Stewart and Lusk studied were are as follows:

(a) Doppler radar provides data measurements of the current weather situation based on the formal, theoretical model of microburst generation
(b) Data are represented (numerically, using bar graphs, colors, or other methods) on computer displays
(c) Forecasters visually interpret those displays
(d) Forecasters extract cues: indicators of the current weather situation and its possible evolution
(e) Finally, forecasters predict the likelihood of microbursts in various locations

The goal of forecasting was a correct judgment of the "probability (0-100%) that a microburst would be produced by the storm under observation within 5-10 minutes" (Lusk, Stewart, Hammond, & Pons, 1990, p. 629) There were six formally defined "precursor cues" that forecasters were to use in forecasting: descending reflectivity core, collapsing storm top, organized convergence above cloud base, organized convergence/divergence near cloud base, reflectivity notch, and rotation (Stewart & Lusk, 1994, p. 63), which were displayed quantitatively but needed to be resolved into judgments such as “questionable,” “ambiguous,” “weak,” or “strong” (Lusk et al., 1990, p. 629). Forecasters also used other indicators including general weather conditions at the time, whether other microbursts had been sited recently in the area and so forth.

There was no one-to-one correspondence between individual data displayed and precursor cues, nor between precursor cues and forecasts. Forecasters vicariously processed multiple data and trends over time to discern precursor cues, and they vicariously processed mutiple precursor cues to make their forecasts. Each forecaster also had metaknowledge in the form of past experience with the model and an assessment of its accuracy and failure modes.

Within this representative experiment, the lens model directly supported quantitative, statistical analysis of forecasting as related to all of the variables above. By running a series of experiments in which data sets were varied, researchers could use the lens model to decompose forecasting judgment at each step in the process to see:

(a) How data, alone and in aggregation, form cues
(b) Effect of data display
(c) How cues function under different conditions
(d) How cues are combined and factored to judge precursor cues
(e) How precursor cues and other data are weighed and interpreted in forming final judgments
(f) Forecaster bias toward or against predicting microbursts
(g) Regression bias: the tendency to alter predictions based on recent experience (like the gambler’s belief in lucky streaks)
(h) Effects of training methods or past instructors on forecasting
(i) Inter-forecaster consistency: similarities and differences between forecasters
(j) Intra-forecaster consistency: did forecasters use consistent criteria across different trials
(k) Cognitive limitations of forecasters, for example, effects of time pressure, or which configurations of data or cues were most difficult to interpret

Using historical data in experiments, it would be possible to measure the actual accuracy of forecasting: how well forecasters would have forecast benchmark situations. As a design tool, this research model could be used to examine and redesign any factor in the data selection, method of data display, procedures, training, and so forth. For example, displays indicate quantitative weather data that forecasters interpret qualitatively. That data could be displayed according to qualitative judgments.

This weather forecasting experiment demonstrates how explicit, formal thinking and implicit, experiential, naturalistic thinking can be analyzed and measured, together in real-life situations. The lens model shows that naturalistic function can be demystified and studied with rigorous quantitative research, in ways that can be useful to design. This method makes it possible to decompose everyday judgment into component cues that trigger interpretations and actions that can be addressed by design, and tested experimentally or measured *in situ*. The experiment is both theoretically and methodologically grounded in an approach that has a history that can be examined. It specifies methodological criteria for studies of normal human cognitive function, and a framework for the interpretation of results (Brunswik, 1956).

Brunswik's lens model demonstrates that naturalistic cognition can be studied along with formal systems as the real world interpretation and use of formal knowledge. His model of representative design demonstrates the value of building an integrated theoretical and methodological framework as a grounded methodology that guides interpretation rather than the ad hoc use of borrowed knowledge.

5. Conclusion

Validating naturalistic cognition will change design's theory of design knowledge, toward one that is more empirical, context sensitive, limited by observation, and that can operate within nonformal, open-ended contexts. It will accord better with everyday existence, in which human beings attempt to make order and function within complex and evolving environments. It pushes design toward the more pragmatist and experience-based theories of knowledge found in the works of Charles S. Peirce, and John Dewey.

The psychological models proposed here are not yet fully formed, but they have rapport with a broad range of findings outside of experimental psychology, and they give a revealing account of their topic. This article points toward the possibility of a more reasonable and satisfying way of thinking about knowledge within design than the current ones. It mitigates much of the current debate by admitting both formal and naturalistic knowledge as valid, each in its own ways and for its own purposes. It also allows a more favorable view of theory in general within design. Dewey provides a practical starting point for considering a theory and its consequences:

> Does it [the theory] end in conclusions which, when they are referred back to ordinary life-experiences and their predicaments, render them more significant, more luminous to us, and make our dealings with them more fruitful? Or does it terminate in rendering the things of ordinary experience more opaque than they were before, and in depriving them of having in "reality" even the significance they had previously seemed to have? (Dewey, 1925, p. 18)

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