Introduction

In daily life, we represent number in many ways: in specialized language forms like counting words, in written inscriptions like Hindu-Arabic or Roman numerals, and in representations of magnitude like number lines or coordinate graphs. There are also the many quantitative expressions that populate everyday speech, like "how much?" and "a lot," as well as temporal and spatial expressions like "before" and "after" or "in front of" and "behind." These varied representational forms – counting words, written inscriptions, graphical representations, everyday speech – afford ways to communicate and think about fundamental numerical ideas like order, magnitude, and arithmetical relations.

In this volume, I take up an issue core to the cognitive sciences: *Where do the numerical representations and ideas about number that we use in daily life come from?* A casual respondent might explain the origins of representations and ideas with statements such as "People learn them in school," or "We learn them from the languages we learn as young children," or "on the job," or "in conversation with others." But such answers beg the question, both historically and developmentally: Where do the representations that are learned in school, on the job, or in conversations with others come from? To pursue answers to this question, I will engage in an analysis of psychological, sociological, and historical processes.

One line of argumentation about developmental origins posits that individuals' representations directly reflect their social worlds – that is, the representations that we use are copies of representational systems used by others – and social history is not raised as a focus of inquiry in those accounts. Learning a community's number system is a matter of copying its representational forms, including (for some theorists) the logic of number embodied in the system. In this experiential view the study of the origins of numerical representations and ideas requires an analysis of the social environments in which individuals are reared. I will argue that an experiential account cannot in itself be adequate. People are exposed to instances of miscounting, errors in arithmetic, and varied speech acts that invoke quantities that can be taken up in many different ways. So, if we simply copy representations and ideas from a social world, how is it that we all end up with a relatively coherent elementary counting and arithmetical knowledge?

Another line of argument about developmental origins holds that our nervous systems are prewired with numerical understandings, or at least with strong predispositions set to support the acquisition of numerical representations. Cognitive neuroscientists use investigative techniques such as brain imaging, single cell recording, and analyses of cognitive performance of patients with focal brain lesions to study relations between brain structures and the processing of numerical information. Their findings reveal that as people and animals cognize number, specific areas of the brain are activated. These investigations and models of brain function can shed light on cortical mechanisms and, more generally, the material bases of cognitive processes. But biological approaches can never be entirely satisfactory, as they fail to deal with such issues as how and why collective representations like number words take form differently over the social histories of different human communities. Moreover, they cannot well address how diverse representations and ideas that are taught in school, that others use on the job, or that speakers use in conversation originate.

These questions about origins of representations and ideas and their varied nuances have been the subject of scholarly inquiry for millennia. In Plato's *Meno*, Socrates attributed numerical ideas to our immortal souls, arguing that ideas are recollected in our mortal lives. Contemporary discussions pursue some of the same issues, and the approaches span modern disciplines and often reach across traditional boundaries. Some of the key contributors to the discussions include those whose principal disciplinary affiliations are in developmental psychology (Piaget, Vygotsky, Werner), cultural anthropology (Barth, Bateson, Boas, Kluckhohn, Kroeber, Sapir, Sperber), linguistics (Chomsky, Croft, Keller, Lakoff, Whorf), epistemology (Fodor, Kant), and the cognitive neurosciences (Dehaene, Gallistel, Gelman, Spelke). My intent in this book is to inject into these discussions both new observations and a cognitive-historical framework that has some potential to integrate diverse strands of inquiry.

Part I of the book situates the overarching problem about origins in contemporary research in the cognitive sciences. I consider (and then reject) traditional dichotomies that treat culture and cognition as separable and often treat cognition as something determined by culture. I put forward my view that such approaches have handicapped productive research on the origins of representations and ideas. Drawing upon previous scholarly work, I sketch an alternative in which cognition and culture are treated as processes with intrinsic relations mutually constituted in activity. Focusing on numerical cognition as an illustration, I argue that *collective practices* – recurring socially organized activities in which cognitive problems emerge – are important arenas for analyses of relations between culture and cognition, and I support my argument with evidence from my research in the Oksapmin region of Papua New Guinea. I show that, in the dynamics of collective practices involving number, people unwittingly reproduce and alter cultural forms of representation to serve numerical functions in public displays of communication and problem solving. "Culture" and "cognition" are not static, nor can they be isolated in analyses of Oksapmin collective practices, either within the brief span of an exchange between two individuals, or over historical time. To understand the origins of number and social history of number, one must examine shifting relations between cultural representational forms and the functions they serve in relation to collective practices of daily life. A treatment of the reproduction and alteration of form-function relations in relation to shifting collective practices over historical time becomes the crux of the analysis in subsequent parts of the book.

In Parts II and III, I report findings on two kinds of collective practices, each occurring at multiple locations in the Oksapmin region and each engaging a shifting network of participants. Part II focuses on analyses of collective practices of economic exchange, tracing shifts in the character of exchanges and numeric forms and functions from the time of initial Western contact in 1938 through the present. I report the distribution of representational forms for number and currency through the Oksapmin community, and their reproduction and alteration over the targeted period of study. Part III focuses on collective practices associated with the introduction of Western schooling in the late 1960s, and the shifts in schooling practices. Again, I report the varied forms of representation used, their distribution, and their reproduction and alteration in classrooms over the period of study.

Part IV integrates the corpus of findings within a comprehensive treatment of the origins of numerical representations and ideas. A central thesis is that collective systems of representations emerge over time as the unintended consequences of local goal-directed actions of individuals. I conclude with a consideration of regulative mechanisms in the generation of form-function relations, and I point to ways that the framework and findings open up new territory for empirical investigation and conceptual analysis in any community.

Part I

The Origins of Number: Enduring Questions

1 Culture-Cognition Relations

My purpose in this first chapter is to review theoretical formulations and empirical work on culture-cognition relations, giving particular attention to accounts of the origins and development of numerical thought. I begin with investigations that treat culture and cognition as separate entities – cognition treated as a skill, intellectual ability, or cognitive structure, and culture treated as a part of a surrounding context. Investigators in this tradition study culture-cognition relations by correlating aspects of the surround with aspects of cognitive functioning; in this process, they explore the way variations in cognition may (or may not) be systematically associated with variations in culture or features of culture. The approach appears reasonable from the perspective of the cognitive and behavioral sciences, and studies have yielded some important findings. Nonetheless, I argue that the approach leads to a dead end, particularly when the questions focus on the origins of numerical representations and ideas. I will argue for a different conceptualization, one that treats both culture and cognition as processes jointly rooted in activity. In the latter half of the chapter, I introduce a new framework and argue for its potential to open up new and more productive paths for inquiry and analysis.

Culture and Cognition: Separate Variables with External Links

Empirical research that treats culture and cognition as separate and independent entities often carries with it two tacit assumptions.[1] One

[1] In this analysis, I draw on similar critiques by others, including Lewin (1931) and Vygotsky (1986) as well as more contemporary authors, like Berger and Luckman (1966), Cole (1996), and Scribner and Cole (Cole & Scribner, 1974; Scribner & Cole, 1981). I also draw on contemporary activity theory (e.g., Engestrom, 1987; Hutchins, 2006).

assumption is that culture is a property of populations, and cultural groups are relatively homogeneous and internally coherent – thus, the French, English, Samoans, or Navaho are distinct cultural groups that are distinguishable in their patterns of daily life, languages, belief systems, economic organizations, and other things cultural, including number systems. A second assumption is that cognition is a capacity of individuals, reducible to cortical structures that are the basis for psychological constructs like memory, motor abilities, perceptual systems, and cognitive structures; such individual capacities can be measured through assessments using cognitive tasks. Conceptualizing culture and cognition as separable domains frames quite naturally questions about their relations: Are variations in culture associated with variations in the cognitive capacities of individuals, and, if so, what is the evidence that cultural variation determines cognitive variations?

The study of culture and number fits quite well into methodological traditions that conceive of culture and cognition as separate domains of inquiry to be related with one another through correlational analyses. From a cultural perspective, the diversity in forms of number representation is astonishing. The Incas, for example, used the *quipu*, a complex system of knotted cords that served to record quantitative information such as gold storage in mines (Ascher & Ascher, 1981). The Mayans developed a place value system, principally for the recording of dates (Closs, 1986b). The Babylonians developed a sexagesimal system, aspects of which have descendants in today's clocks (Menninger, 1969). There are myriad lesser-known cultural forms for number representation that have emerged within and across the continents of Africa (Zaslavsky, 1973), the Americas (Closs, 1986b), and Asia (Menninger, 1969). Some of the variation still exists, despite increasing globalization. Indeed, on the island of New Guinea alone, there are more than 800 cultural and/or language communities using a wide range of culture-specific counting systems. Some of these groups use body parts, others use specialized words for number, and still others use physical tokens. Within each type there are many variations, and some groups use multiple types (Lancy, 1983; Laycock, 1975; Lean, 1992; Mimica, 1988; Saxe, 1981d; Saxe & Posner, 1982; Wassmann & Dasen, 1994).[2]

Scholars have made efforts to abstract the dimensions of cultural variation in numerical forms of representation. Analyses have come from varied disciplines, including anthropology (Closs, 1986a; Crump, 1990; Lean, 1992), linguistics (Hurford, 1987), psychology (Gelman & Gallistel, 1978;

2 For compendia, see Lean (1992), Menninger (1969), Smith (1925), and Zaslavsky (1973).

Lancy, 1983), and economics (Harper, 2010). Proposed dimensions include the following:

1. *Material/nonmaterial properties of number signs.* In contemporary Western life, we use a specialized register of words to refer to numbers – count words like "one, two, three," et cetera in English. But other communities use forms that are not strictly verbal: In the Mt. Hagen area of Papua New Guinea, for example, one of the Melpa's systems consists of physical tallies (Saxe, 1983), and many central highlands groups in Papua New Guinea make use of body parts (Lean, 1992). Over the course of world history, remarkable forms of number representation have emerged with varied material embodiments, whether the Inca's knotted cords, Neolithic notched bones, or the cuneiform records of ancient Mesopotamia.
2. *Number of number signs in systems*. Representational systems use different numbers of elements in counting. Some, as in the Western use of Hindu-Arabic orthographic numerals (0, 1, 2, …, 9), include a potentially infinite number of representations made possible by base-structure principles (for example, 1001). Others make use of a restricted number of number names, and indeed it has been reported that cultural groups in Brazil, including the Pirahã (Everett, 2005) and the Munduruku (Pica, Lemer, Izard, & Dehaene, 2004), have minimal if any representations for exact quantities. In the case of the Pirahã, Everett reports that the group's language lacks a singular-plural morphology and their counting numbers are restricted to not more than two (Frank, Everett, Fedorenko, & Gibson, 2008).
3. *Cyclic structure of signifiers*. A feature of most contemporary number systems is the use of elementary signs to generate composite signs. Lean (1992) refers to the simplest systems as two-cycle, that is, the use of two elementary signs, with additional number signs being composites of these. Thus the first and unique elements are signs for one and two, with consecutive numbers taking the form of $3 = 2 + 1$, $4 = 2 + 2$, $5 = 2 + 2 + 1$, and so on (Hurford, 1987; Lean, 1992). In his documentation of South Pacific groups, Lean describes systems that employed a range of such structures, including two-, four-, five-, six-, and ten-cycle organizations (Lean, 1992). As I will discuss in Chapter 2, one of the Oksapmin's two number systems is a modified two-cycle "conversational" number word system not linked to the body. The system is used to represent five numbers (one to five), in which the word for two is *yota* and the word for four is *yota*

yota. (The Oksapmin also use a body-part counting system, making use of 27 points on the body as signs for numbers.) Languages for which Ancient Chinese is the ancestral language have a ten-cycle organization, as does English. In the case of English (and in many other Romance and Germanic languages), the expressions "eleven" and "twelve" are irregular in the ten-cycle structure.

4. *Numerical functions of signifier use*. Signifiers serve different numerical functions within a group and across groups. For example, in the English-speaking world, we use our own register of number words to serve nominal functions (bus routes), ordinal functions (positions in a sequence), and cardinal functions (the number of objects in a group), to name a few. Forms may take on function-specific properties. In English, for example, word forms for cardinal and ordinal numbers differ, as in "four" and "fourth."

The widespread use of forms of number representation, coupled with striking cultural variation in the forms, has been the focus of varied positions regarding culture-cognition relations. Let's consider four prominent ones.

1. *Cultural Forms of Number Representation Determine the Numerical Thought of Individuals*

The first position identifies cultural forms of number representation as the principal determinant of quantitative thought. The logic of number in language becomes the logic underpinning the numerical thought of the individual. This position, of course, is a variation of the Whorfian position applied to numerical thought (Whorf, 1956). This focus leads to identifying cultural variation in representational forms for number and then associated variations in numerical capabilities of individuals.

In research on number with the Pirahã, a remote Amazonian group, Daniel Everett (2005, 2007) and Peter Gordon (2004) initially took up this position, arguing that language differences in number (along with differences in the structure of the indigenous language) determine thinking differences among individuals and across cultures. Everett, a linguistic anthropologist, found representations that the Pirahã used for number to be very limited. Gordon, a cognitive psychologist, followed up the linguistic findings by administering to Pirahã adults tasks that required numerical comparisons and reproductions of arrays of varying set sizes, and he found that these adults rarely produced successful solutions beyond very