are usually taught in elementary geology courses or in conjunction with more advanced courses in igneous petrology. It is also well suited for self-study or for a one-semester course in volcanology for seniors or graduate students.

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Capacities of Young Children

The Child's Understanding of Number. ROCHEL GELMAN and C. R. GALLISTEL. Harvard University Press, Cambridge, Mass., 1978. xvi, 260 pp. $13.50.

The topic of this book, the development of number concepts, has been an important one in developmental psychology. The approach to the subject that has predominated in recent years is the Piagetian. Piagetian theory revolves around the presence (or absence) of certain logical operations that develop in the 6- to 12-year range. Piagetians characterize the number (and other) behavior of younger children primarily in terms of what the children cannot do. Such children are referred to as "preoperational": they are at a stage of development that precedes the concrete-operational stage in which they will be able to perform the various kinds of operations that form the core of the Piagetian theoretical and measurement apparatus. Consider, for example, conservation ability. Suppose a preoperational child is presented with two rows of toys each of which contains five toys. In one row the toys are spaced one inch apart; in the other they are spaced two inches apart. The child will fail to "conserve quantity" and will state that the row with the toys spaced farther apart contains more toys than the other row.

The authors of the present book believe that the cognitive capacities of so-called preoperational children have been underestimated, and they set out to discover what such children *can* do. The emphasis in their approach is upon understanding the representations, processes, and strategies that constitute number ability. The authors indeed show that three-year-olds and even some two-year-olds have rudimentary counting abilities that they can use in simple counting tasks.

Another difference worth noting between the approaches of Piaget and of Gelman and Gallistel is a methodological one: whereas the approach of Piaget and his co-workers tends to be clinical, based upon rather informal observations of very small numbers of children, Gelman and Gallistel's is basically experimental, relying upon larger numbers of subjects in carefully controlled experiments—though they also make astute use of observation to supplement the findings gleaned from experiments.

Underlying Gelman and Gallistel's research is a set of five principles, mastery of which they consider to underlie the ability to count.

1) *The one-one principle*. A distinct tag must be assigned to each object in an array, and only one tag may be assigned to each object. (The authors emphasize that these tags need not be conventional numerals. They take as evidence of mastery of the principle in particular, and of counting in general, the assignment by young children of letters of the alphabet to successive objects. Satisfaction of the principle does not even require that the letters or numbers be assigned in conventional order, so long as the assignment of tags to objects is unique.)

2) *The stable-order principle*. The tags must be arranged in a stable (repeatable) order, and the number of tags must be as large as the number of objects in the array.

3) *The cardinality principle*. The tag applied to the final object in an array must represent the number of objects in that array. (This principle involves recognition of a special property of the last tag used, namely that this tag represents the cardinality of the array of objects.)

4) *The abstraction principle*. The preceding principles can be applied to any array or collection of entities, whether physical or nonphysical. (The importance of this principle lies in the inability of very young children to recognize that nonphysical entities, such as the number of minds in a room, can be counted in the same way that physical entities can be counted. As the authors also point out, very young children often do not recognize the possibility of counting together members of ludicrous sets, such as the set of all minds and all chairs in a room.)

5) *The order-irrelevance principle*. The order in which objects in an array are tagged is irrelevant to the number of objects in the array.

These principles are not proposed as unitary processes or components of performance. Rather, acquisition and utilization of each principle is alleged to consist of several component processes, for example, partitioning of items into already-counted and to-be-counted sets and tagging of the items in the case of the one-one principle. Moreover, application of principles can be partial. For example, children's ability to apply the first three, "how-to-count," principles, is a function of set size. The authors conclude that many two- and three-year olds cannot count reliably beyond three or four. Nevertheless, the children show some differentiation among higher quantities in making absolute judgments about them. Finally, abilities to apply the various principles are not fully independent. Application of the cardinality principle, for example, presupposes successful application of the one-one and stable-order principles.

The first three chapters of Gelman and Gallistel's book deal with some general issues in developmental metatheory and methodology. To a general reader or a developmental psychologist whose interest is not in number concepts per se, these chapters may be the most valuable ones in the book. They are clearly written and deal with some key issues in developmental research. They contain, for example, a discussion of the unfortunate tendency to characterize preschoolers in terms of what they cannot rather than what they can do; a discussion of the failure of the task-centered approach to psychology, in which research becomes a study of tasks rather than of the psychological structures and processes used in their performance; and a discussion of the role of training studies in psychological research. Although some of the points the authors make have been made elsewhere in the psychological literature, they seem to be quickly forgotten and need to be stated and restated. I recommend this first set of chapters to anyone interested in conducting developmental research.

Chapters 4 through 10 and chapter 12 of the book present the basic theoretical framework, methodologies, and results of research on number concepts. Although theory and data from a variety of sources find their way into the presentation, the overwhelming emphasis in these chapters is upon the Gelman research program of the last decade. Despite their sometimes technical content, these chapters are lucid and usually easy to follow.

The approach of chapter 11 seems at times to be at variance with that of the rest of the book. Whereas the other chapters subordinate mathematical formalisms to psychological ones, this chapter seems to do the reverse. Although interesting and edifying, it seems more like a lesson in formal mathematical theory than like one in psychological theory. The book concludes with a concise (three pages) summary of most of the major points.

On the whole, I found this book to be an excellent one. I will mention a few reservations, however.

First, some more detailed, if speculative, discussion of the role of early number concepts in later quantitative concepts would have been helpful. For example, do individual differences in older children's and adults' quantitative abilities derive from individual differences earlier on in the understanding and application of the principles suggested by Gelman and Gallistel, or must the source of variance in the performance of older individuals be sought elsewhere?

Second, the book does not make clear just what the psychological status of the principles is. Why, for instance, do the elementary component processes (a separate listing of which would have been helpful) combine into these particular principles and no others? Are these particular principles psychologically or arithmetically "natural" in some sense that other principles would not be? Is their existence something to be assumed or something to be proven? Further, what exactly does partial attainment of a principle mean? Is there some set of more elementary principles that are attained in an all-or-nothing manner? These and other such questions could have been addressed more fully.

Third, whereas Piagetian theory may ascribe too little to the preoperational child, I am concerned that Gelman and Gallistel are sometimes willing to ascribe a bit too much. In some cases, I would have preferred more stringent demonstrations of particular forms of competence or inferred performance. For example, the authors propose four criteria for satisfying the cardinality principle (pp. 95–96): (i) "the child counted (correctly or incorrectly) the number of items in the array and repeated the last tag: for example, 'two, sixteen; sixteen" ; (ii) "the repetition of the last tag was sometimes given emphatic stress"; (iii) the child assigned number words "to each of the items in the set on one trial, for example 'one, two, three,' and shifted to a simple indication of numerosity of the same set without overt counting on a later trial"; (iv) the child "assigned the correct value to the set without counting aloud." These criteria are formulated in a somewhat less restrictive way than I might have chosen. My major concern, however, is with the fact that the authors judged a child to have mastered the cardinality principle if he or she met just one of them. In fact, table 8.3 suggests that satisfaction of the criteria was by no means all-or-none. In this and other cases, I would have been more comfortable with a requirement for satisfaction of at least two criteria, or at least more detailed presentation of the number of children satisfying each criterion so that the reader could make up his or her own mind regarding satisfaction of the various principles.

Fourth and finally, I am concerned that this research, like virtually all pioneering research on psychological phenomena, relies too heavily upon formal systems that do not correspond to psychological reality. The authors note that they "compare the preschooler's arithmetic principles to the modern formal system of arithmetic in order to highlight various aspects of the preschooler's principles. The modern formalism is the only available backdrop, because no one, so far as we know, has formalized what might be called the layman's system of arithmetic" (p. 180).

In the history of psychological research such formalisms have often turned out to be red herrings. In research on propositional and syllogistic reasoning, for example, significant progress seems to have been made only after the principles of formal logic were dropped as bases for the laws of thought. In the quantitative domain, the research of Tversky and Kahneman on probabilistic and statistical reasoning in adults was striking in part because adults seem not to reason according to any accepted principles of probability and statistics. Thus, at least one goal for the next decade of research seems to emerge from the research of Gelman and others. The need now is for the missing characterization of the "layman's system of arithmetic," and for a similar characterization for children of different ages.

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