General Article

THE NATIVIST-EMPIRICIST CONTROVERSY IN THE CONTEXT OF RECENT RESEARCH ON SPATIAL AND QUANTITATIVE DEVELOPMENT

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Demonstrations of cognitive competence in preschool children and infants played an important role in the waning influence of Piagetian theory and the rise of nativism. Arguments and data favoring modularity have further buttressed the case for nativism. This article reviews evidence concerning early competence and modularity in the spatial and quantitative domains, as well as the role of experience in development. This evidence provides little reason to support nativist claims in either domain.

Introductory textbooks (e.g., Berk, 2002) still present Piaget's theory of cognitive development at great length, along with a few experiments that challenge his point of view and a brief discussion of some alternative theories such as information processing approaches. However, such presentation does not reflect the dominant currents in contemporary thinking about cognitive development. Piagetian theory has been out of favor for some time, and, although various approaches have been pursued in its stead, nativism has been a dominant—perhaps the dominant—approach to thinking about cognitive development over the past two decades.

Challenges to nativist thinking have taken various forms. Some writers have focused on methodological critiques of particular empirical phenomena seen as support for nativism (e.g., Bogartz, Shinskey, & Speaker, 1997; Haith & Benson, 1998). Other investigators have argued for alternative overarching views of cognitive development (e.g., Elman et al., 1996; Gopnik & Meltzoff, 1997; Karmiloff-Smith, 1992; Siegler, 1996). The purpose of this article is to take a very short historical tour of research in two domains in which it has been claimed that there is innate core knowledge: spatial and quantitative development. The discussion focuses on highlighting questions about the nativist point of view rather than proposing detailed interactionist theories. (For more specific discussion of the building of mature competence in each domain, see longer treatments: on spatial development—Campos et al., 2000; Newcombe & Huttenlocher, 2000; on quantity and number—Mix, Huttenlocher, & Levine, 2002; Simon, 1997, 1999; Sophian, 1997).

The case for innate core knowledge regarding space and number has rested essentially on two research thrusts. First, in the early-competence tradition, there have been reports of impressive spatial and quantitative ability in preschoolers and even infants. Data of this sort played an important part in creating doubts about Piagetian theory, the predecessor to nativism as the dominant view of cognitive development. They were seen as support for nativism essentially by default. If Piaget's account of development was wrong, and if preschoolers and even infants had astonishing abilities, perhaps they came prepared with these abilities from the beginning. Second, there have been findings regarding spatial and quantitative processing that have been argued to suggest that infants come equipped with core knowledge in the form of domain-specific modules that are impervious, at least initially, to modification by other modules or systems. Hypotheses of this kind have, especially recently, been central to the case for nativism, or at least particular versions of it. This article examines and critiques each of these two research thrusts. The discussion then turns to a third argument for nativism, namely, that experience is unimportant to cognitive development (Spelke & Newport, 1998).

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EARLY COMPETENCE

There are many studies in the spatial and quantitative domains that suggest that preschoolers have impressive skills. For instance, a great deal of work on visual perspective taking demonstrates that young children are not egocentric in the way that Piaget and Inhelder (1948/1967) proposed. They realize that other people viewing from different vantage points do see something different from what they see and can even work out in detail what that is, given certain task formats (for a review, see Newcombe, 1989). Similarly, research in the domain of quantity shows that preschoolers are much more skilled than Piaget predicted. For example, in Gelman's (1972) seminal "magic" study, she showed children two plates (e.g., one with two mice and one with three mice), saying that one plate was the "winner" (e.g., the plate with two mice). The plates were then covered and shuffled, and the mice were surreptitiously rearranged. Preschool children proved capable of picking the correct plate as the winner, despite the rearrangement of the mice.

Surprising capabilities in preschoolers are impressive, but even more striking have been demonstrations of infants' and toddlers' abilities. For example, in the spatial domain, Huttenlocher, Newcombe, and Sandberg (1994) and Bushnell, McKenzie, Lawrence, and Connell (1995) questioned Piaget's hypothesis that early spatial coding is nonmetric and topological, using hiding tasks with toddlers. Children in these experiments showed excellent metric accuracy in searching for hidden objects in continuous spaces. Further work showed that even infants of 5 months have some ability to code metric extent (Newcombe, Huttenlocher, & Learmonth, 1999). They look longer when an object emerges from a spot 8 or 12 in. away from where it was hidden than when it emerges from its hiding location.

In the quantitative domain, there are widely reported findings of competence in infancy. Habituation experiments have demonstrated that infants who are shown slides of a certain number of objects until reaching a habituation criterion dishabituate (as measured by looking time) when they see slides of a different number of objects (Starkey & Cooper, 1980; Strauss & Curtis, 1981). Starkey, Spelke, and Gelman (1990) provided even more powerful support for very early understanding of number. They showed infants slides of either two or three objects, while two or three drumbeats played in the background. The infants were more likely to look at the slide of two objects if there were two drumbeats, and to look at the slide of three objects if there were three drumbeats. Such a cross-modal matching response seems to show a deeply abstract notion of number. Yet another kind of support for early quantitative competence came from Wynn's (1992) findings suggesting that infants showed an understanding of simple addition and subtraction.

Competence in preschoolers and even in infants cast a cloud of doubt over Piaget's theory because such findings created problems for Piaget's descriptions of development—in the spatial case, his claim that development of spatial representation progresses from initial topological representation to projective and euclidean representation, and in the quantitative case, his claim that understanding of number is based on construction of the system of logical thinking called concrete operations. In challenging Piaget, however, research of this kind had a consequence not always intended by investigators: strengthening the case for nativism by suggesting that core competence might be available as soon as it was testable at all. The infant findings especially had this effect, because it often seemed difficult to imagine how some of the documented abilities could be constructed during environmental interactions.

Research on early competence, although necessary and illuminating in many ways, does not, however, decisively favor nativism. First, findings that point to important developmental change should not be forgotten in the fascination with early competence. Second, some of the most well-known results regarding early competence are not empirically secure. Third, and most important, data on early competence are not, in principle, theoretically decisive in themselves. On the one hand, even late developmental changes may not truly challenge nativist theory, if such changes result from biological maturation or from additions to the child's behavioral repertoire that can be argued to be relatively trivial. On the other hand, even very early competence could, on closer analysis, turn out to result from environmental input.

Continued Development

An interesting aspect of some of the data presented already is that, although they give impressive evidence of the prowess of young children, they also indicate limitations on early ability. For instance, although children as young as 3 years can answer certain kinds of perspective-taking questions, it is equally true, but often forgotten or ignored, that children cannot pick the right picture or model of another person's viewpoint until the age of 9 or 10 years. Before 5 years, they cannot even pick a picture showing their own viewpoint when given an array of alternatives containing the correct items in different spatial arrangements (Newcombe & Huttenlocher, 1992). Similarly, children's ability in Gelman's (1972) magic experiment is evident only for small numbers, up to 3 or perhaps 4—young children cannot deal with large numbers, such as 5 or above, even given a child-friendly paradigm (e.g., Feigenson, Carey, & Hauser, 2002).

Findings on the abilities of toddlers and infants also indicate limitations on the extent of their competence. For instance, evidence that toddlers and infants code metric extent in continuous space, although certainly at odds with a traditional Piagetian view, is less impressive in the context of the fact that, initially, children do not show the ability to use a set of distal landmarks to establish spatial location. In the animal literature, this ability is termed place learning and is often assessed using the Morris water maze, in which animals are put in a circular enclosure filled with milky water, so that they cannot see the stand that will bring refuge from swimming. Rats can find the stand after a certain period in development, but not before (Nadel, 1990). Newcombe, Huttenlocher, Drummey, and Wiley (1998) found an analogous transition in humans at about 21 months, and there is long-continued development after that, until the age of 6 or 7 years (Overman, Pate, Moore, & Peuster, 1996). Such a pattern of data suggests a fundamental transition in development to the ability to perform place learning, which is the most powerful, flexible, and mature kind of spatial coding.

There is also new evidence of fundamental change after infancy in the quantitative domain. One instance involves the ability to perform cross-modal matching, the very task that has been used to give impressive support for an early abstract number concept. Surprisingly, given the infant data, Mix, Huttenlocher, and Levine (1996) found that 3-year-old children perform at chance on an auditory-visual matching task involving number. Their problem was not in understanding the demands of the matching task itself, because they could do a visual-visual matching task quite well. Similarly, Mix (1999) has recently shown that there are marked differences in young children's ability to perform even visual-visual matching, depending on the visual similarity of the things to be matched. Thus, whatever the infant data show, they do not index a robustly available and functionally useful ability to do matching tasks involving number. A second, similar, instance of fundamental change after infancy involves addition and subtraction of small numbers. Despite Wynn's (1992) findings with infants, Huttenlocher, Jordan, and Levine (1994) showed that children younger than 3 years were baffled by a very simple nonverbal task assessing addition and subtraction.

Empirically Insecure Findings

When data indicate that infants can apparently do something that toddlers cannot, there might be various ways to explain why. For instance, one could point to the passive nature of infant looking as opposed to the active nature of the matching required of toddlers. But such theorizing may not be needed at all, in the cases of some lines of development, because there is question about the capabilities of infants. One question in point concerns the fact that findings on preschoolers' difficulties with cross-modal matching of number seem to fit oddly with the reports of cross-modal matching in infants. Moore, Benenson, Reznick, Peterson, and Kagan (1987) found cross-modal mismatching rather than matching by infants, as did Mix, Levine, and Huttenlocher (1997) in one study. In another study, Mix et al. (1997) found no difference at all in how much time infants looked at slides that matched versus failed to match auditory presentations in number of stimuli.[1]

Habituation studies' support for infant understanding of number can also be questioned. Clearfield and Mix (1999) controlled for an important factor that had never been adequately examined before in such studies, namely, contour. They found that if infants are habituated to slides of two objects and then are shown three objects, with the same amount of contour, they do not show rebounds in looking time. However, they do show increased looking time if shown two objects having more contour than the two in the habituation set (see Fig. 1). So, it seems that infants respond to the amount of contour, not to the number. This result has since been replicated and extended (Clearfield & Mix, 2001; Feigenson, Carey, & Spelke, in press).

Theoretical Indecisiveness

Observations of early competence may be questioned, as I have done, but one also has to ask whether the matter is theoretically decisive in the fashion often assumed. On the one hand, striking early competence could possibly depend on environmental input, a matter to which I return later. On the other hand, limitations in evidence for early competence and findings of late emergence of certain abilities may not contradict nativism, for several reasons. One reason is that late emergence may be a maturational phenomenon, an argument relating to the

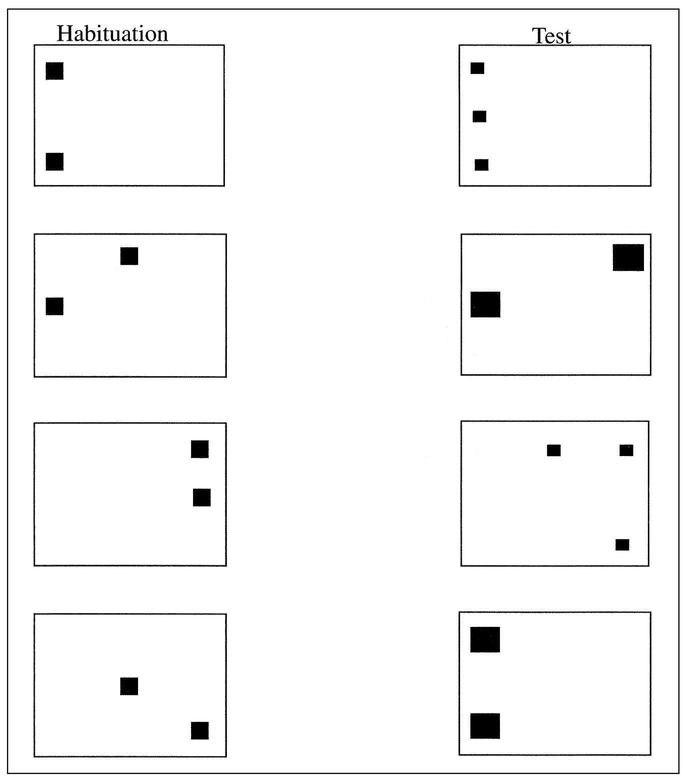

Fig. 1. Sample stimuli from Clearfield and Mix (1999). The first and third pairs vary number but keep contour length constant; the second and fourth pairs vary contour length but keep number constant.

1. Although one might argue that a finding of mismatching still shows sensitivity to number, the result may also indicate a "file drawer problem." That is, if there is truly no difference, many studies showing no difference may be hidden in people's file drawers rather than published, with the only published studies being those in which a difference was obtained by chance. The use of one-tailed tests in the original report renders this a special concern.

problem of environmental input, to be discussed shortly. There are two other lines of argument used by nativists against the importance of late developmental change that I consider now.

First, emerging abilities are sometimes seen as relatively trivial. For example, with respect to visual perspective taking, making a correct choice in the picture-selection version of the task may depend on learning strategies such as "focus on one object in the array" (Newcombe & Huttenlocher, 1992). Some investigators might argue that acquisition of such strategies is not of fundamental interest. However, a rebuttal along these lines betrays a peculiar way to think about developmental change. The abilities that take time to emerge are far from trivial in terms of functional significance. It is odd to dismiss as uninteresting the kind of development that takes a nascent ability manifest in only a very restrictive set of circumstances to a mature ability that allows for actual accomplishment.

Second, some nativist proposals have recently taken the tack of recognizing the existence of developmental change, while still emphasizing core knowledge (e.g., Hermer & Spelke, 1994, 1996; Spelke & Newport, 1998). Such proposals generally conceptualize developmental change as the emergence of modules (Leslie, 1987) or the linkage of initially separate modules (Hermer & Spelke, 1996). In such ways, nativist theorists can encompass the idea that not all relevant adult abilities are present at birth, while still retaining nativism in the proposition that emergence or linkage of innately given modules constitutes the basis for what developmental change there is. Thus, I must now turn to the second line of argument for nativism to be considered in this article, namely, modularity.

MODULARITY

Any proposal for modularity must be specific about the type of module postulated. There is detailed discussion of innate modularity in the spatial domain (Hermer & Spelke, 1994, 1996). Proposals that quantitative knowledge is innately modular (Dehaene, 1997; Wynn, 2000) are somewhat less specific. In this section, these domains are discussed in turn. First, I present direct evidence against the existence of an informationally encapsulated or impenetrable geometric module. Second, I address the less specific claims about innate modularity in the quantitative domain by presenting evidence that there may be a common initial underpinning for what eventually divides into separate lines of quantitative and spatial development. Findings of domain-generality pose a challenge to one of the key tenets of a modularity version of nativism.

Doubts About a Geometric Module

Although there is much discussion of modularity in the cognitive development literature, only a few proposals are specific enough to evaluate empirically. Prominent among them is the proposal for a geometric spatial module (Hermer & Spelke, 1994, 1996). The argument for such a module is based on studies with 18- to 24-month-old toddlers who were asked to look for an object hidden in one of four identical corners in a rectangular room, after having been spun around and disoriented. In an all-white room, the children looked equally often in the correct corner or the reverse corner (diagonally across from the correct corner).

This important finding demonstrates an early competence in using geometric information, because the behavior must be based on coding the relative length of the walls and their relation to each other (i.e., "the toy is in the corner where the short wall is to the left of the long wall"). However, the claim of modularity comes not from these data, but from a different aspect of the experiment, a condition in which one of the walls of the rectangular room was colored. Surprisingly, although the children noted and seemed to remember the colored wall, they still confused the correct corner and the reversal corner. Their lack of use of the color cue to disambiguate the two geometrically identical corners suggests impenetrability, one of Fodor's (1983) proposed characteristics of a module. Specifically, Hermer and Spelke (1996) claimed that the data suggest a "mechanism that is informationally encapsulated and also task specific, which are two hallmarks of modular cognitive processes" (p. 195).

Learmonth, Newcombe, and Huttenlocher (2001) have, however, gathered data casting doubt on the existence of a geometric module, using the same paradigm as Hermer and Spelke (1996). Learmonth et al. found that toddlers could in fact go to the correct corner when various kinds of landmarks were added to a large room with all-white walls. The children succeeded in a room with a recessed bookcase and a door in diagonally opposite corners. They could go to the correct corner either when it was directly marked (i.e., in front of the bookcase or door) or when it was unmarked (i.e., across from the bookcase or door). They also succeeded with only the bookcase present, recessed centrally into the short wall. Most surprisingly, they succeeded with a colored wall, exactly the same landmark used by Hermer and Spelke. Learmonth, Nadel, and Newcombe (2002) have shown that the key to these findings is room size: Data supporting modularity are found only in very small rooms, as used by Hermer and Spelke. Thus, although there is certainly interesting evidence that very young children are able to encode the length of walls and the relation between the coded dimensions, there is no reason to believe that this information is encapsulated. It is indeed integrated with other relevant information about the spatial world.

Domain-General Starting Points

There is evidence that there are strong beginnings shared between the domains of space and number, casting doubt on hypotheses of innate modularity in either domain. Clearfield and Mix's (1999) finding that infants are sensitive to amount of contour suggests the importance of "quantity of stuff" as indexed by spatial extent. Their finding is reminiscent of the evidence that 5-month-olds code spatial extent in the infant sandbox studies (Newcombe et al., 1999). Gao, Levine, and Huttenlocher (2000) conducted a study that further links what has been thought of as the spatial domain to what has been considered the quantitative domain. In one experiment, infants looked at large glass test tubes either 1/4 or 3/4 filled with colored liquid. Infants habituated to one quantity dishabituated when the quantity was changed. Furthermore, in a second experiment in which liquid was added to the cylinder, infants reacted with increased looking time when the amount did not change as would be expected. That is, infants showed an ability to judge the amount of liquid that there ought to be. Another way of saying this, which makes clear how closely linked the spatial and quantitative domains are early in life, is that infants have the ability to judge how long the vertical line of colored liquid ought to be. Thus, a basic sensitivity to amount, whether amount of liquid, contour, or distance in the sandbox, could provide a common departure point for both quantitative and spatial development. Differentiation of domains could occur for any one of several reasons, as discussed by Mix et al. (2002).

Analog representations of magnitude continue to be important in quantitative reasoning through preschool (Huntley-Fenner & Cannon, 2000). Children of 4 years are able to identify correspondences of magnitude ratios in proportionality tasks (Huttenlocher, Newcombe, & Vasilyeva, 1999; Sophian, 2000). Such abilities form an important underpinning of mature spatial and quantitative reasoning, including the ability to deal with fractions. Fractional reasoning has sometimes been hypothesized to be inherently difficult to master, but recent data suggest this may not be the case (Mix, Levine, & Huttenlocher, 1999; Sophian, 2000).

An alternative account of early quantitative sensitivity emphasizes the importance of object files rather than analog amount (e.g., Feigenson et al., 2002). For the present purposes, however, the important point is not which of these approaches is correct. Rather, it is striking that in both theories, there is a domain-general mechanism for early quantitative sensitivity. Object files are, after all, used extensively in visual processing and in physical reasoning, so their use in early "number" tasks would also be inconsistent with the modularity hypothesis.

Spelke and Dehaene (1999) argued against the viewpoint that there are domain-general beginnings for quantitative reasoning, arguing for a strong innate modularity in understanding number. However, their discussion actually outlined a spatial underpinning for number development, in brain areas in the left and right intraparietal sulcus. They wrote that there is "the possibility of a considerable overlap [of the circuitry supporting numerical reasoning] with other visuospatial functions that are known to yield very similar activity patterns in the intraparietal sulcus, such as mental rotation and other spatial-coordinate transformation tasks" (p. 365). They suggested that numerical and spatial processing might be "intricately intertwined in the parietal lobe." Surely it is simpler to postulate that the foundation of both later spatial and later quantitative abilities lies in the ability of a certain brain area to code extent and quantity, rather than to hypothesize that there are separate modes of processing which just happen to be physiologically intertwined.

ENVIRONMENTAL INPUT AND DEVELOPMENTAL CHANGE

To this point, I have raised doubts about the evidence for two of the bases for believing in nativism, early competence and modularity. However, could there be a domain-general or nonmodular nativism that emphasizes early competence but also acknowledges developmental change? Considering this question leads to a consideration of causes and mechanisms of developmental change. For such a position to be nativist, one would have to argue that the cause of developmental change is environment-independent maturation. Otherwise, the position would be a domain-general interactionist one, acknowledging early competence but also postulating the relevance of environmental input in creating cognitive development. The role of environment in cognitive development is the question Spelke and Newport (1998) emphasized as a key one for the empiricist-nativist debate.

Recent evidence gives reason to believe that environmental input is, in fact, vital to cognitive development. However, much of this input is usually encountered in the normal environment and not very variable across individuals. (That is, the developing child can "expect" to encounter these experiences, to use the terminology of Greenough, Black, & Wallace, 1988.) Consider three examples from motor development. First, crawling allows for different kinds of interactions with the environment than are possible for the nonmobile infant, and crawling experience is well established as the cause of transitions in spatial location coding (Campos et al., 2000). Second, skills learned in one performance context, such as perceptions of the affordances of surfaces or the use of cues to find hidden objects, may have to be relearned or at least recalibrated when motor skills change (Adolph, 2000; Clearfield, 2001), suggesting the vital importance of experience to the development of competence. Third, Needham (2000), examining the ability of 3.5-month-olds to use object features to determine if a display consists of two separate objects (e.g., a cup on top of a saucer) or is one fused whole, found that infants who had active object-exploration skills did better at this task than infants who had not yet begun to use their hands to explore their environments.

Motor development is only one example of expectable environmental input that is key for normal cognitive development. There are other examples from the more purely sensory domain. Maurer, Lewis, Brent, and Levin (1999) studied children whose vision was obscured by congenital cataracts, sometimes in one eye, sometimes in both, and whose operations to remove the cataracts were done at different ages. Their data show clearly how crucial normally expectable input can be to the development of normal vision. Within the spatial domain specifically, Rieser, Lockman, and Pick (1980) have shown that adventitiously blind individuals perform better at distance judgments than congenitally blind individuals, suggesting the importance of expectable early experience for basic spatial functioning.

One might argue that universal changes provoked by expectable environmental input depend more on nature than on nurture. But this argument entails that the only abilities that could be considered truly developing are those for which environmental input is variable and uncertain. Yet fundamental abilities cannot be left to chance, if an organism is to have evolutionary success. The key question in the nativist-interactionist controversy is whether environmental interactions are or are not required to produce mature competence. Nativists believe that adaptation was ensured by highly specific built-in programs, whereas interactionists suggest that inborn abilities do not need to be highly specific because, for central areas of functioning, the environmental input required for adaptive development is overwhelmingly likely. Evidence favors the latter solution to the adaptational problem.

Not all cognitive development is experience expectant. There are other kinds of changes that do show individual differences in input and consequent individual differences in eventual achievement. Consider the acquisition of the ability to use maps, compasses, and other navigational aids, to use a spatial example, or the ability to perform arithmetical calculation, to use a mathematical example. These abilities build on basic competencies available to young children. However, such abilities also develop fully only with intensive culturally mediated instruction. Learning mechanisms in the context of instruction include opportunities to observe the results of using various coexisting strategies (Siegler, 1996), as well as observational learning and scaffolded support from experts (Rogoff, 1990).

CONCLUSION

Nativism in the spatial and quantitative domains rests, historically, first on findings of early competence. More recently, there have been claims that innate modular knowledge provides the building blocks for cognitive development and that environmental input is insignificant for development. However, the first claim is not securely established, ignores well-known facts about developmental transitions, and is, in any case, irrelevant to the nativist-empiricist debate unless supplemented by knowledge about developmental mechanisms. The second claim is quite dubious—there is simply no clear evidence supporting modularity in the two domains examined here, and some good reason to doubt it. The third claim is not so much insecure as insufficiently evaluated. We are only beginning to examine the role of input in cognitive development and the mechanisms that lead to developmental change. What is known, however, about the spatial and quantitative domains suggests an important role for the environment, albeit not always a variable and unpredictable one.

Thus, one key to imagining a viable new interactionism is recognizing the interest of experience-expectant interactions (Greenough et al., 1988). Evolution may plausibly operate not through the provision of specific content-laden modules, but by giving infants the equipment that, in interaction with the world, will (almost) inevitably develop the sorts of structures that are needed for adaptive function. More recently, the cultural innovations made by human beings, such as maps and number systems, have altered and amplified the course of cognitive development. Acquisition of these systems takes place in exchanges that allow children to experiment with approaches to problems, observe expert solutions, and be supported by experts in their initial performances.

In summary, the more one considers the debate between nativism and empiricism, the more one concludes that neither extreme possibility is viable. John Locke and Noam Chomsky are two thinkers often presented as clear examples of empiricist and nativist approaches to the origins of knowledge. However, Locke recognized that infants are innately endowed with sensory equipment and a propensity for forming associations, and Chomsky was certainly aware that exposure to a particular language in the environment is vital for becoming, for example, a Chinese speaker rather than a speaker of Swahili. So each man, in his own way, is a type of interactionist, if interactionism is simply defined as recognizing a role for both nature and nurture in development. Rather than endlessly replaying the empiricist-nativist debate, researchers need to get on with the detailed work of proposing exactly how starting points in infancy—stronger than those postulated by Piaget—are transformed into mature competence—perhaps not quite in the way Piaget imagined, but nonetheless in generally interactional ways.

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