To build a rich understanding, the researchers conducted a 12-month ethnographic effort including more than 200 site visits and more than 500 pages of data entries in field notebooks. They conducted open-ended interviews with children individually and collectively and carried out semistructured interviews. The participating children built personal documents, including narratives and images (photographs). Finally, the researchers themselves kept diaries designed to record a day in the life of a particular participant. The researchers conducted laboratory studies with factorial ANOVA designs to test, among others, the impact of computing tools (3D vs. 2D) and collaboration (singles vs. dyads) on the ability to transfer skills to distal-level standardized items. Such experiments demonstrated that the Quest Atlantis software supports learning; other parts of the four-year study produced theoretical conjectures, including an expanded taxonomy of motivations involved while children learn through playing games.

As a result of their work, the researchers found to have been building "petite generalizations." Petite generalizations are refined understandings of the patterns that researchers have encountered and that others in the field may likewise encounter. Most importantly, the ultimate product expanded its impact as it was redesigned, fitted, and adapted, together with the users, to the contingencies of each local setting.

The design experiment offers many advantages to the psychologist interested in designing and studying complex interventions in their naturalistic settings. Design experiment may be understood as an integrated approach to research and development that includes qualitative and quantitative approaches. This, then, allows design scientists to simultaneously (a) adapt interventions by taking into account local contingencies and (b) test hypotheses in a scientifically rigorous way that allows weeding out chance variations from true cause-and-effect relations. Design experiments thereby provide opportunities to meet the two major goals educational psychologists and learning scientists have set themselves: understanding knowing and learning scientifically and developing interventions that have a long shelf life because they meet the needs of the participants.

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Wolff-Michael Roth

DEVELOPMENT OF CORE KNOWLEDGE DOMAINS

From where does knowledge come? Scholars interested in this question have delineated three possible sources: experience, culture, and evolution. Knowledge obtained through experience is knowledge derived from one's own observation and exploration of the physical world. Knowledge obtained through culture is knowledge initially derived by someone other than oneself but acquired through the process of cultural transmission. Knowledge obtained through evolution is knowledge of a genetic origin, endowed in humans by natural selection due to its utility to our prehominid ancestors.

Although few would dispute the claim that humans acquire knowledge through experience and culture, many have disputed the claim that humans have acquired knowledge through evolution. Indeed, this claim has remained controversial since its origins in ancient Greek philosophy and its revival in eighteenth-century Enlightenment philosophy (Stich, 1975), though, in recent years, it has gained substantial support from empirical studies of infant cognition and animal cognition. Drawing on the findings of such studies, Spelke (2000) has proposed that innate knowledge, or "core knowledge," can be identified by three defining features: (1) domain-specificity, or a restriction on the types of objects and relations the system can represent; (2) task-specificity, or a restriction on the goals and objectives the system can accomplish; and (3) encapsulation, or operational independence from other systems of knowledge.

Core knowledge is thought to guide learning in a variety of ways, from guiding the interpretation of one's early experiences to constraining the scope of one's early inferences to providing the foundations of one's future knowledge. Although there is some controversy as to what domains of knowledge are innate and what domains are not, scholars have pointed to at least five possibilities: (1) the domain of objects and their physical properties, (2) the domain of agents and their psychological properties, (3) the domain of space and its geometric properties, (4) the domain of number and its arithmetic properties, and (5) the domain of living things and their functional properties.

Evidence of early emergence, cross-species homology, and cross-cultural universality are stronger for some domains (e.g., the domain of number) than for others (e.g., the domain of living things). Nevertheless, there is ample evidence that all five domains emerge prior to formal instruction. Below are charted the development of three such domains: the domain of space, the domain of number, and the domain of living things. For each domain, characterizations are provided of (a) the domain's initial knowledge state, and (b) the domain's first major restructuring. Following these characterizations, this entry discusses general similarities and dissimilarities among the early transitions within each domain.

THE DOMAIN OF SPACE

Spatial cognition consists of a variety of competencies, including navigation, depth perception, landmark encoding, and reorientation. Here, the focus is on reorientation, or the process of realigning one's mental representation of the environment with the environment itself, as there is much evidence that reorientation involves an evolutionarily ancient mechanism present in both human and nonhuman animals.

The earliest studies of reorientation were conducted with rats (Cheng, 1986; Margules & Gallistel, 1988). In these studies, food-deprived rats were shown food being hidden in one of four corners of a rectangular enclosure. The rats were then removed from the enclosure and disoriented via rotation. Upon their return to the enclosure, the rats searched for the hidden food in either the correct corner or the geometrically equivalent corner, that is, the corner diagonal to the correct corner, which shares with the correct corner the property of being to the left of a short wall and to the right of a long wall (or vice versa, depending on the particular hiding location). Amazingly, the disoriented rats did not use the nongeometric properties of their enclosure, like wall color or wall odor, to guide their search, even though these properties uniquely specified the food's location and were readily used as navigational cues by fully oriented rats. Similar results have since been obtained with monkeys (Gouteux, Thinus-Blanc, & Vauclair, 2001), fish (Sovrano, Bisazza, & Vallortigara, 2002), and chicks (Sovrano & Vallortigara, 2006).

Studies of reorientation in humans have revealed striking similarities between how disoriented children search for hidden toys and how disoriented rats search for hidden food (Hermer & Spelke, 1994; 1996). In these studies, children aged 18 to 24 months were shown a toy being hidden in the corner of a rectangular room and were then disoriented by being spun around with their eyes closed. Following disorientation, children tended to search for the toy in one of two locations: the correct corner or the geometrically equivalent corner. This behavior persisted even in rooms where the location of the toy was uniquely specified by a distinctive nongeometric cue: a blue wall. Thus, children, like rats, do not initially take nongeometric information into consideration when reorienting themselves, and they continue to ignore such information until around the age of 7 (Hermer-Vazquez, Moffet, & Munkholm, 2001).

Children's sensitivity to geometric information–and only geometric information–in reorientation tasks appears to be limited to a particular kind of geometry: the geometry of extended, three-dimensional surfaces. Studies that have explored children's reorientation behavior in open space have found that children do not reorient by the geometry of moveable objects within that space (Gouteux & Spelke, 2001). Moreover, studies that have explored children's reorientation behavior in different kinds of enclosures have found that children who fail to reorient by differences in wall color will nonetheless reorient by differences in wall shape (Wang, Hermer, & Spelke, 1999). The fact that children's reorientation is sensitive to some features of the environment (i.e., wall location, wall shape) but not others (i.e., wall color, object locations) suggests that the mechanism responsible for this behavior attends only to stable features of the environment unlikely to change from day to day or from season to season.

As mentioned previously, older children (and adults) do not reorient like rats. Instead, they reorient by both geometric information (e.g., wall location) and nongeometric information (e.g., wall color). What allows older children, but not younger children, to use such information? One hypothesis, suggested by Hermer & Spelke (1996), is that remembering the location of an object relative to nongeometric features of the environment requires encoding such relationships in language. In support of this hypothesis, Hermer-Vazquez and colleagues (2001) have shown that children's production of the words *left* and *right* is highly correlated with their use of nongeometric information in reorientation tasks. Moreover, Hermer-Vazquez, Spelke, and Katsnelson (1999) have shown that adults' use of nongeometric information in these same tasks is significantly impaired when adults are required to listen to and repeat a tape recording of continuous speech, thereby preventing them from producing phrases like "left of the blue wall." These data imply that the development of spatial cognition is tied to the acquisition of spatial language, though the exact nature of this relationship has yet to be determined.

THE DOMAIN OF NUMBER

Numerical cognition, like spatial cognition, appears to be ubiquitous throughout the animal kingdom (Gallistel, 1990), and evidence of numerical cognition in humans can be found as early as six months of age. For instance, habituation studies have shown that 6-month-old infants can discriminate visual arrays of 8 dots from visual arrays of 16 dots (Xu & Spelke, 2000). Infants of this age have also been shown to discriminate auditory sequences of 8 tones from auditory sequences of 16 tones (Lipton & Spelke, 2005). By 9 months of age, infants are not only able to keep track of different numerosities but are also able to add and subtract those numerosities (McCrink & Wynn, 2004). That is, if they see five objects go behind a screen followed by another five objects, they expect to see ten objects when the screen is lowered, not five, as evidenced by a difference in how long they look at each outcome.

How do infants' number representations compare to the number representations of children and adults? Although some (e.g., Gallistel & Gelman, 2003) have argued that infants' representations form the basis of all subsequent mathematical knowledge, others (e.g., Le Corre, Van de Walle, Brannon, & Carey, 2006) have argued that these representations are too imprecise to support an understanding of integers and the operations defined over them. Evidence of such imprecision comes from the finding that although 6-month-old infants can discriminate 8 dots from 16 dots and 8 tones from 16 tones, they cannot discriminate 8 dots from 12 dots or 8 tones from 12 tones. Imprecision of this nature decreases with age, but it never disappears altogether (Barth, Kanwisher, & Spelke, 2003), which has lead many to posit the existence of two distinct systems for representing number: (1) a nonverbal system capable of representing approximate numerosity, present from infancy through adulthood and shared with many nonhuman animals, and (2) a verbal system capable of representing exact numerosity, unique to humans and acquired around the age of 3 in the form of counting.

Because counting involves the mastery of a representational system not supported by core knowledge, learning how to count is not easy. In fact, studies of how children learn to count have revealed that children acquire this ability in a succession of small, discrete steps (Wynn, 1990; Carey, 2004). First, children learn their language's "count list," or their language's list of words used to denote sets of increasing numerosity (e.g., "one," "two," "three"). Second, they learn how to apply this list to an array of objects by labeling each object in the array with one, and only one, word in the count list. Third, they learn that, when applying the count list to an array of objects, the last number word reached when counting corresponds to the cardinal value of the set. In other words, they learn that the word *four* refers not only to the fourth object encountered during the counting routine but also to the total number of objects encountered up to that point.

Evidence that children learn these three skills in stages, rather than in tandem, comes from dissociations in children's performance on simple numerical reasoning tasks. For instance, children are able to recite the count list long before they are able to apply it consistently to an array of objects. Likewise, children are able to apply the count list to an array of objects long before they realize that the last word reached when counting constitutes an answer to the question, "How many are there?" In fact, children go through a 6- to 9-month period during which time they are able to count a collection of objects but are not able to retrieve a particular number of objects from the collection. That is, when asked to retrieve a particular number of objects, they grab a handful at random and make no attempt to coordinate their knowledge of counting with their estimation of numerosity.

Of crucial importance to learning how to count is being exposed to a count list. Some cultures, such as the Pirhaha and Munduruku tribes of the Amazon rain forest, do not have count lists, and the members of those cultures cannot therefore keep track of exact numerosities (Gordon, 2004; Pica, Lemer, & Izard, 2004). For instance, when shown a collection of objects and asked to select a particular number (indicated nonverbally with fingers or sticks), Piraha adults tend to produce a close match, but not an exact match, to the requested number, implying that the only system they have for representing numerosity is the imprecise system they inherited via evolution.

THE DOMAIN OF LIVING THINGS

Evidence for a core knowledge of living things comes not from studies of infant cognition or animal cognition but from studies of cross-cultural universals. These studies have revealed that, across cultures, children's early understanding of animals appears to be structured around three metaphysical commitments: (1) vitalism, or the belief that living things require energy in order to function; (2) essentialism, or the belief that living things possess an internal "essence" that determines their outward appearance and behavior; and (3) taxonomic relatedness, or the belief that living things can be organized into inferentially rich, multilevel hierarchies.

An early-developing commitment to vitalism is evident from studies of children's understanding of digestion, respiration, and circulation (e.g., Inagaki & Hatano, 1993; Morris, Taplin, & Gelman, 2000). In these studies, 5- and 6-year-old children are presented a variety of explanations for an activity like eating and are asked to select the best one. Although adults tend to prefer mechanistic explanations (e.g., we eat food "because we take the food into our body after the food is changed in our stomach"), children tend to prefer to vitalistic ones (e.g., we eat food "because our stomach takes in energy from the food"), regardless of their cultural upbringing. In line with these findings, preschool-aged children recognize that animals, but not artifacts, grow (Rosengren, Gelman, Kalish, & McCormick, 1991) and that consuming food is necessary for growth (Inagaki & Hatano, 1996).

Studies demonstrating an early-developing commitment to essentialism have focused not on children's understanding of metabolic processes but on their understanding of inheritance (Gelman & Wellman, 1991; Sousa, Atran, & Medin, 2002). In these studies, 3- and 4-year-old children are told stories about a baby animal who was raised by adult animals of a different species (e.g., a cow raised by pigs) and are asked to predict which properties it would possess as an adult: the biological properties of its birth parents (e.g., a straight tail and a diet of grass) or the biological properties of its adopted parents (e.g., a curly tail and a diet of slop). Regardless of cultural upbringing, children tend to predict that the baby animal will grow to possess the biological properties of its birth parents, not its adopted parents.

Evidence of a universal commitment to taxonomic relatedness comes from studies of how individuals from different cultures categorize the flora and fauna of their local ecologies (Atran, 1990; Berlin, 1992). These studies have found that individuals the world over classify living things into hierarchies that typically include the ranks of "kingdom" (e.g., plants, animals), "life form" (e.g., trees, birds), "generic species" (e.g., oaks, parrots), and "folk-specific species" (e.g., white oaks, African Gray parrots). These ranks constrain a variety of biological inferences—from inferences about how to extend known properties to novel organisms to inferences about how to extend novel properties to known organisms—for children and adults alike. Indeed, children as young as 2 consistently use their knowledge of taxonomic relations to constrain their extension of known properties to novel animals (Gelman & Coley, 1990).

Despite the above evidence for an early-developing conception of living things, children have been shown to experience great difficulty grasping other aspects of biological knowledge, including the very meaning of the words *alive* and *dead* (Piaget, 1929; Carey, 1985). For instance, when children aged 8 and younger are quizzed on their knowledge of what is alive and what is not, they classify many things that are alive (e.g., flowers, tress, bugs, worms) as "not alive" and many things that are not alive (e.g., the sun, the wind, clocks, fire) as "alive." Moreover, children of this age are reluctant to extend properties true of all living things (e.g., has cells, has babies, gets sick) to plants and insects.

These misconceptions suggest that children do not initially understand life as a process of maintaining and regulating bodily functions and death as the cessation of that process. Consequently, they confuse life with animacy, observability, or functionality, and they confuse death with inanimacy, unobservability, or nonfunctionality. Acquiring a correct conception of life appears to be tied to acquiring a mechanistic conception of biological functioning. Support for this claim comes from a study by Slaughter and Lyons (2003), in which children were questioned on their beliefs about death both before and after a teaching intervention designed to impart a mechanistic understanding of the internal workings of the human body. Before the teaching intervention, children revealed a number of misconceptions about the nature of death (e.g., that death can be avoided, that death can be reversed). After the teaching intervention, these same children revealed significantly fewer misconceptions, even though the intervention itself did not broach the topic of death.

TRANSCENDING CORE KNOWLEDGE

Each of the developmental transitions described above share at least two commonalities. First, all three transitions involve overcoming structural limitations in the architecture of core knowledge, whether they be limitations in the information used to reorient oneself in the environment, limitations in the precision with which numerosities are represented, or limitations in the properties used to identify living things. Second, all three transitions involve the acquisition of culturally constructed knowledge, whether it be knowledge of the words *left* and *right*, knowledge of a count list, or knowledge of the inner workings of the human body.

Commonalities aside, each developmental transition exemplifies a slightly different type of knowledge acquisition. For instance, children's transition from geometry-based reorientation to landmark-based reorientation is more strategic than conceptual in nature, for this transition involves learning to attend to a spatial relationship that had previously been neglected (i.e., "left of the blue wall") rather than learning to conceptualize space in an entirely new way. Children's transition from a vitalistic biology to a mechanistic biology, on the other hand, is more conceptual than strategic in nature, for this transition involves learning to conceptualize living things in an entirely new way (i.e., as self-sustaining, self-regulating machines) rather than learning to attend to a particular property of living things that had previously been neglected. The transition from an approximate representation of number to an integer-based representation of number also exemplifies a conceptual change, though the kinds of concepts that change within the domain of number (i.e., nominal-kinds concepts) are very different from the kinds of concepts that change within the domain of biology (i.e., natural-kinds concepts. Whether, and how, such a difference matters to the process of conceptual change itself has yet to be determined.

SEE ALSO *Concept Development; Theory of Mind.*

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Andrew Shtulman

DEWEY, JOHN
1859–1952

It is fair to say that the philosopher John Dewey, who was born before the Civil War in 1859 and died in 1952 just before the Eisenhower administration, has had the greatest single impact on American education of any scholar in history. Dewey, more than anyone else, is associated with the alternative to traditional education known as child- or learner-centered education. Dewey's contribution to education was part and parcel of his contribution to shaping the intellectual life of the time in which he lived.

Portrait of John Dewey. COLUMBIANA COLLECTION, COLUMBIA UNIVERSITY LIBRARIES.

Dewey took the discipline of philosophy more seriously than most, borrowing five hundred dollars from an aunt after graduating from the University of Vermont in 1897 to pursue a doctorate at Johns Hopkins University—this at a time when most philosophers at colleges were ministers with seminary degrees. Dewey's first academic job was at the University of Michigan, which was headed by a family friend. He spent 10 fruitful years in Ann Arbor, laying the groundwork for an approach to philosophy that he was able to apply to education in 1894 when he moved to the newly founded University of Chicago. Dewey was lured away from Chicago in 1904 and spent the remainder of his long career at Columbia University, retiring from that institution in 1930 but continuing to serve as an active professor emeritus until shortly before his death in 1952 at the age of 92.

There are at least three key ideas associated with John Dewey's approach to education that continue to resonate with progressive or, in current usage, *constructivist* U.S. educators. In fact, all three of the great reform movements in U.S. education, in the 1930s, 1960s, and 1990s, highlighted variations on these three themes: Individualism, the notion that it is up to the individual child, with guidance from the teacher, to make sense of his or her own experience; readiness, the notion that the child will learn when he or she is ready to learn; and pragmatism, the notion that the worth of learning lies in its instrumental value.

Individualism has repeatedly been central to reform efforts as a reliance on the pedagogy of personal experience, a belief that individuals must be the instigators of their own learning. The teacher, according to this view, works within the students' own experiential workspace as it were. The goal here, it should be emphasized, is a specific type of conceptual learning, the type that individual students induce from their own particular or discrete experience. The teacher, it is thought, in this child- or learner-centered approach, can at best only indirectly influence the inferential process of induction, pointing out to the learner patterns in particular data that become concepts and suggesting names for these patterns in a facilitative rather than a controlling way.

The second tenet of reform-oriented education in the United States is a corollary to the first: This is the need for the teacher to be watchful in fulfilling the facilitative role often described as being a *guide on the side.* Because student need is thought to drive the process