Figure 1 (Gardner). Array for testing chimpanzee Basso (Marbe 1917). Note that virtually all child versus chimpanzee comparisons cited by Penn et al. allow tester to cue testee in this way.

Burkardt doubted that Basso knew arithmetic. Asked what he believed Basso was doing, Burkardt said, "She reads my mind." Marbe tested this hypothesis by asking the trainer to give Basso a series of arithmetic problems and think wrong answers. The result was decisive. Basso repeatedly gave the answer that Burkardt was thinking, regardless of the correct answer in arithmetic. She succeeded at mind reading where she failed at arithmetic.

Had Marbe stopped here, some current theorists might cite Basso as a pioneer demonstration of a chimpanzee with a theory of mind. Instead, Marbe administered further tests showing that Basso selected the card that Burkardt looked at. The trainer himself was unaware that he was gazing at particular cards and was sure that he never gave any hints whatsoever. Earlier, Pfungst (1911/1965) showed that Hans, a German horse, solved arithmetic problems and spelled out German words by following the gaze of human interlocutors who were also unaware that they were hinting. The horse also failed tests when his trainer thought he should fail. That is, the experimenter hints innocently shaped results to conform to experimenter expectations, as a sculptor shapes a lump of clay. After these pioneering studies, experimental procedures to control for inadvertent hints became standard in comparative psychology (B. Gardner & Gardner 1989, Fig. 4.1; Harlow 1949, Fig. 1; Warden & Warner 1928).

Oddly, a wave of recent claims of evidence for noncontinuity fail to use any controls for experimenter hints. This failure of method is apparent in virtually all of the experimental evidence that Penn et al. cite. Herrmann et al. (2007) is a very recent example. Fortunately, an online video published by *Science* clearly shows that experimenters were in full view of the children and chimpanzees they tested. Differences in experimenter expectations or rapport between experimenter and subject easily account for all results.

Interested readers can verify the persistence of this experimental error in evidence of noncontinuity cited throughout Penn et al.'s target article.

Intelligent nature and nurtured intelligence. Additionally, nonexperiments compare caged chimpanzees – lucky if they have a rubber tire to play with or a rope to swing from – with human children from suburban homes. Most modern psychologists would expect caged human children to lose rather than develop cognitive ability. Indeed, the longer

chimpanzees live in cages, the lower they score on cognitive tasks (Povinelli et al. 1993; Tomasello et al. 1987).

Credible comparisons depend on comparable conditions. In sign language studies of cross-fostered chimpanzees (R. Gardner & Gardner 1989), homelike conditions simulated the rearing environment of human children. Chimpanzees acquired signs in spontaneous conversational interactions with their human foster families the way human children acquire their native languages. Conversations were embedded in the casual interactions of daily life (e.g., Bodamer & Gardner 2002; Chalcraft & Gardner, 2005; B. Gardner & Gardner 1998; R. Gardner & Gardner 1989; Jensvold & Gardner 2000; Shaw 2001; Van Cantfort et al. 1989). They are comparable to dialogues in similar research with human children because cross-fostered chimpanzees and human children carry on conversations under similar conditions.

Patterns of development were comparable to human patterns. Vocabulary, sentence constituents, utterances, phrases, and inflection, all grew robustly throughout five years of cross-fostering. Growth was patterned growth, and patterns were consistent across chimpanzees. Comparable measurements paralleled in detail characteristic patterns reported for human infants (Bodamer & Gardner 2002; B. Gardner & Gardner 1998; Jensvold & Gardner 2000; Van Cantfort et al. 1989). Development was slower than human development without reaching an asymptote.

Mind-numbing drill. Penn et al. discuss the tube-trap problem invented by Visalberghi and Limongelli (1994) as a demonstration of cognitive discontinuity. In fact, Visalberghi and Limongelli subjected their monkeys to highly repetitive drill, a traditional procedure for inducing stereotyped habits that interfere with human as well as nonhuman problem solving. R. Gardner and Gardner (1998, pp. 270–87) discuss decades of evidence for the universally mind-numbing effect of drill on human and nonhuman problem solving found in experiment after experiment for at least a century. Luchins and Luchins (1994) reviews nearly fifty years of closely parallel negative effects of repetitive drill on human problem solving.

Relational language supports relational cognition in humans and apes

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Abstract: We agree with Penn et al. that our human cognitive superiority derives from our exceptional relational ability. We far exceed other species in our ability to grasp analogies and to combine relations into higher-order structures (Gentner 2003). However, we argue here that possession of an elaborated symbol system – such as human language – is necessary to make our relational capacity operational.

Penn et al. make a far-ranging and convincing case that the ability to store and process higher-order relations is a defining feature of human cognition. We agree that our extraordinary relational ability is a central reason "why we're so smart" (Gentner 2003). But unlike Penn et al., we also accord central importance to language and other symbol systems.

In our view, human cognitive powers stem both from inborn relational capacity and from possession of a symbol system capable of expressing relational ideas. These two capacities

form a positive feedback cycle. Analogical processes are integral to language learning (Casenhiser & Goldberg 2005; Gentner & Namy 2006; Tomasello 2000), and relational language fosters relational ability. We support this latter contention with four points.

1. *Relational language fosters the development of relational cognition.* Loewenstein and Gentner (2005) found that preschool children were better able to carry out a challenging spatial analogy when spatial relational terms (such as *top middle bottom*) were used to describe three-tiered arrays. We suggest that the relational terms induced a delineated representation of the spatial structure, which facilitated finding relational correspondences between the two arrays (see also Gentner & Rattermann 1991). Further, these representations endured beyond the session: Children retained this insight when retested days later, without further use of the spatial terms. Spelke and colleagues have also demonstrated effects of relational language on children's performance. For example, preschool children who know the terms *left* and *right* outperform their peers in relocating a hidden object placed relative to a landmark (Hermer-Vasquez et al. 2001).

2. *Children who lack conventional language are disadvantaged in some relational tasks.* One example is homesigners – congenitally deaf children of hearing parents who, deprived of a conventional language, invent their own "homesign" symbol systems (Goldin-Meadow 2003). Using the three-tiered arrays described above, we investigated homesigners in Turkey and found that (1) these children appeared not to have invented consistent terms for spatial relations, and (2) they performed substantially worse on the spatial mapping task than did hearing Turkish-speaking children (matched for performance on a simpler spatial task) (Gentner et al. 2007). Likewise, deficits in numerical ability have been found in Nicaraguan homesigners, whose invented language lacks a systematic counting system (Spaepen et al. 2007). Numerical deficits are also reported for the Pirahã people, who possess a "*one, two, many*" number system (Gordon 2004).

3. *Possessing relational symbols facilitates relational reasoning among nonhuman animals.* Research by Thompson et al. (1997) (discussed in Penn et al.'s article, but with an opposite conclusion) provides evidence for this claim. Five chimpanzees were given a relational-match-to-sample (RMTS) task, a notoriously difficult task for nonhuman animals (see Fig. 1):

XX

AA   BC

Figure 1 (Gentner & Christie).   The relational match-to-sample task.

Four of the chimps had previously had symbolic training – either same/different training or numerical training – and one had not. Only the four symbolically trained chimpanzees succeeded in the RMTS task – a crucial point that is not noted in Penn et al.'s discussion. Instead, Penn et al. link this RMTS task with array-matching tasks that are passed by naive animals (Wassermann et al. 2001). But two large arrays of identical elements (e.g., ooooooooo and kkkkkkkk) can be seen as more alike than either is to an array of all-different elements (e.g., vlfxrtdei) on the basis of similar texture (cf. Goldmeier 1972), rather than via relational processing. In contrast, the two-item case does not afford a textural solution. It requires matching the SAME (X,X) relation to the SAME (A,A) relation (instead of to the DIFF (B,C) relation). This kind of relational reasoning is facilitated by relational symbols in chimpanzees just as in humans.

4. *The gap between humans and other apes develops gradually through the influence of language and culture.* Human children do not begin with adult-like relational insight. Rather, children show a relational shift from attention to objects to attention to relations (Gentner 1988; Halford 1987). For example, in the RMTS task with the same triads as described earlier, 3-year-olds respond randomly; they do not spontaneously notice relational similarity. Importantly, however, children show far greater relational responding if known labels (*double*) or even novel labels are used during the task (Christie & Gentner 2007).

Dramatic evidence for the developmental influence of language and culture on relational representation comes from research by Haun et al. (2006). They compared humans from different language communities with the other great apes (chimpanzees, bonobos, gorillas, and orangutans) on a locational encoding task. All four ape species used an allocentric (external) frame of reference. Interestingly, German 4-year-olds showed the same pattern. But older humans diverged in a language-specific way. Dutch 8-year-olds and adults used an egocentric frame of reference, consistent with the dominant spatial frame used in Dutch (and German). In contrast, Namibian 8-year-olds and adults, whose language (Hai‖om) uses a geocentric frame of reference, encoded locations allocentrically (specifically, geocentrically). These findings suggest a gradual developmental divergence of humans from great apes; and they further suggest that language is instrumental in this divergence.

Further points. Penn et al. cite the fact that deaf children of hearing parents invent their own homesign systems (Goldin-Meadow 2003) as evidence that external language is not needed. But as discussed earlier, homesign systems fall short precisely where our position would predict: in the invention and systematization of relational terms. Penn et al. also cite aphasics who retain relational cognition despite losing the ability to speak. This is problematic for accounts that hinge on the online use of internal speech. But in our account, the great benefit of relational language is that it fosters the *learning* of relational concepts, which then serve as cognitive representations.

Darwin was not so wrong. We agree with Penn et al. that relational ability is central to the human cognitive advantage. But the possession of language and other symbol systems is equally important. Without linguistic input to suggest relational concepts and combinatorial structures to use in conjoining them, a human child must invent her own verbs and prepositions, not to mention the vast array of relational nouns used in logic (*contradiction, converse*), science (*momentum, limit, contagion*) and everyday life (*gift, deadline*). Thus, whereas Penn et al. argue for a vast discontinuity between humans and nonhuman animals, we see a graded difference that becomes large through human learning and enculturation. Humans are born with the potential for relational thought, but language and culture are required to fully realize this potential.

The missing link: Dynamic, modifiable representations in working memory

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