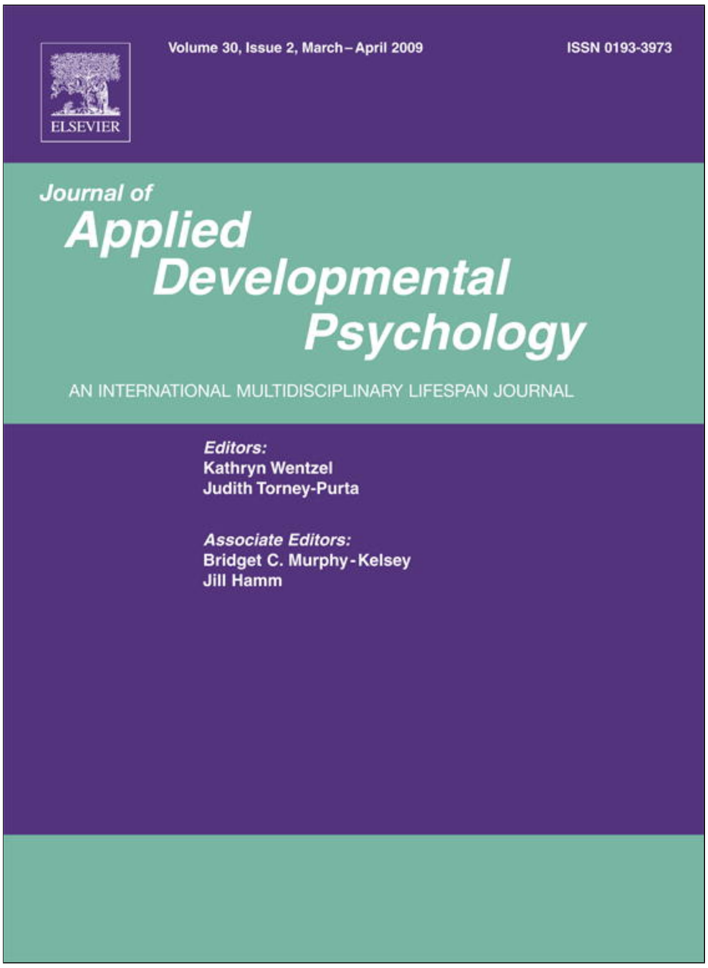


Volume 30, Issue 2, March–April 2009
ISSN 0193-3973

ELSEVIER

Journal of
Applied
Developmental
Psychology

AN INTERNATIONAL MULTIDISCIPLINARY LIFESPAN JOURNAL

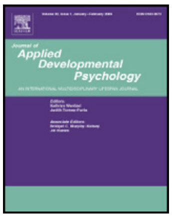
Editors:
Kathryn Wentzel
Judith Torney-Purta

Associate Editors:
Bridget C. Murphy-Kelsey
Jill Hamm

Journal of Applied Developmental Psychology 30 (2009) 92–102

Contents lists available at ScienceDirect

Journal of Applied Developmental Psychology



Children's behavior toward and understanding of robotic and living dogs ☆

Gail F. Melson [a,*], Peter H. Kahn Jr. [b], Alan Beck [a], Batya Friedman [b], Trace Roberts [a,1], Erik Garrett [a], Brian T. Gill [c]

[a] *Purdue University, 101 Gates Road, West Lafayette, IN 47907-2020, USA*
[b] *University of Washington, Seattle, WA 98105, USA*
[c] *Seattle Pacific University, Seattle, WA 98119, USA*

ARTICLE INFO

Available online 19 November 2008

Keywords:
Children
Robots
Technology
Cognitions
Behavior
Animals

ABSTRACT

This study investigated children's reasoning about and behavioral interactions with a computationally sophisticated robotic dog (Sony's AIBO) compared to a live dog (an Australian Shepherd). Seventy-two children from three age groups (7–9 years, 10–12 years, and 13–15 years) participated in this study. Results showed that more children conceptualized the live dog, as compared to AIBO, as having physical essences, mental states, sociality, and moral standing. Children also spent more time touching and within arms distance of the live dog, as compared to AIBO. However, a surprising majority of children conceptualized and interacted with AIBO in ways that were like a live dog. For example, over 60% of the children affirmed that AIBO had mental states, sociality, and moral standing; and children were as likely to give AIBO commands as a living dog. Discussion broaches whether it is possible that a new technological genre is emerging that challenges traditional ontological categories.

1. Introduction

Robotic ‘pets,’ technological emulations of companion animals, have become increasingly complex and broadly disseminated. They are part of a trend toward *personal embodied agents*, or *social robots*, computer technology embedded within forms that emulate biological entities. The most sophisticated, Sony's AIBO, is marketed as an “ideal companion with real emotions and instinct” (www.sony.com). Despite this claim, we know very little about how children (or adults) perceive and respond to this emerging technology. According to Turkle (1995), many children who regularly use personal computers and computer-based toys come to think of them not only as machines, but also as psychological objects that combine mind activities (talking, singing, spelling, doing math), interactive style, and an opaque surface. In treating computers “as if” they were minded social actors (Reeves & Nass, 1998), children may be developing behaviors toward and understandings of a domain of objects they may perceive as neither purely artifacts nor living beings.

Social robots, such as AIBO, may be even more likely than desktop computers to raise boundary questions about domain membership. According to Fong, Nourbakhsh, and Dautenhahn (2003) and Breazeal (2003), social robots share a number of features that reliably elicit perceptions of animacy and causality in children and adults: they are personified, embodied, adaptive, and autonomous. They can learn, communicate, use natural cues, respond to emotions in humans, self-organize, and pull on people in psychological rather than artifactual ways (Kahn, Freier, Friedman, Severson, & Feldman, 2004).

The ability of social robots to self-initiate and self-organize movement may be particularly important. When two-dimensional shapes appear to move in smooth trajectories toward an apparent goal, preschoolers as well as older children and adults will

---

☆ We thank the following for assistance with statistical analyses and the following for assistance with data collection, transcript preparation and coding: Brian Gilbert, Migume Inoue, Oana Georgescu, and Jocelyne Albert.

* Corresponding author. Department of Child Development and Family Studies, Purdue University, 101 Gates Road, West Lafayette, IN 47907-2020, USA.
E-mail address: melsong@purdue.edu (G.F. Melson).

[1] Now at 15404 Cumberland Gap Road, New Castle, VA, USA.

0193-3973/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.appdev.2008.10.011

interpret the shapes as intentional agents, with personality and emotions (Scholl & Tremoulet, 2000). Apparent goal-directed behavior in videos of unfamiliar blobs elicits biological and psychological attributions in both 5-year olds and adults (Opfer, 2002). In their review, Rakison and Poulin-Dubois (2001) argue that the roots of the animacy–inanimacy distinction lie in infancy and stem from a variety of perceptual properties, including self-propelled vs. caused motion, smooth vs. irregular line of trajectory, action at a distance vs. action from contact, contingent vs. non-contingent pattern of interaction, and causal agent vs. recipient. In concert with such perceptual cues, infants employ skeletal causal principles to judge the motion paths of novel objects as propelled from within (the "innards principle") and hence, animate, or by external force (the "external agent" principle) and thus, inanimate (Gelman, Durgin, & Kaufman, 1995). Social robots exhibit all of the properties associated with animacy.

A second line of research, which S. Gelman (2004) calls the theory view of development, suggests hypotheses about children's perceptions of and behaviors toward social robots. Appearance and movement of unfamiliar objects give children clues about category assignment as belonging to the biological, psychological, or artifactual domains. Once an object is identified as belonging to a domain, essentialist beliefs lead children to infer ‘essences,’ that is, distinct unseen properties that reflect the underlying nature that imparts category identity. Consistent with this view is the construct of enabling domain-specific constraints (Gelman & Williams, 1998). Core domains of thought divide objects into animate and inanimate. Judgment that an object belongs to a particular domain guides learning by suggesting particular interpretations of information. Thus, when 3–5 year olds are presented with realistic color photographs of unfamiliar animals, plants and machines, labeled as such, 4 and 5 year olds select appropriate internal parts for animals (e.g., bones) versus machines (e.g., batteries) (Gottfried & S. Gelman, 2005). Preschoolers view self-initiated movement (“it moves by itself”) as part of the essence of animals but not machines (S. Gelman & Gottfried, 1996) and attribute the causal mechanism of such movement to “vital energy” or life force (Inagaki, 1997). According to Inagaki & Hatano (1996), children generally construct a vitalist biology by ages 5–6 and an intuitive particulate theory of inanimate matter between ages 8 and 12.

Given the importance of domain assignment for inferences about object characteristics, children's perceptions about social robots are of interest. Robotic dogs, by design, share features both of robots and of living dogs. As robotic pets become more highly interactive and “lifelike,” they may blur categorical distinctions between technological artifact on the one hand and biological being and psychological agent on the other. Judgments about machines are "quintessentially ambiguous," according to Gelman et al. (1995, p.181) because machines appear to move on their own, but lack biomechanical motions or adaptations to environmental perturbations. However, social robots like AIBO are designed to mimic biomechanical motions and have relatively sophisticated adaptation capacities, compared to other machines. Thus, one goal of the present study was to examine whether children viewed a robotic dog as possessing or lacking technological, biological, or psychological properties. Moreover, we sought to determine if attributes of the robotic dog were justified in terms of domain category membership or properties. For example, a child might state that the robotic dog could not eat because it “did not have a mouth” (lacks a biological property) or “was just a machine” (category as artifact).

Additionally, we examined use of analogical reasoning in children's judgments about the robotic dog as further evidence for children's constructs. As Gentner (1989, 2005) and Goswami (2001) point out, children build new object categories by noting both perceptual and relational commonalities. AIBO has perceptual commonalities with both animals (tails, ears and body shape of a dog) and machines (the grey metal exterior of a machine). Similarly, AIBO shares relational commonalities with animals and machines. The robotic dog appears to make eye contact and track movement but also ‘communicates’ with flashing lights and musical sounds. The extent to which children liken the robotic dog to something else through analogical reasoning provides further evidence of domain assignment.

When animal robots emulate interactive animal companions such as dogs, they may elicit the human repertoire of behavior, cognitions, and affect generally directed toward living pets. Approximately 75% of all U.S. households with children younger than 18 years of age also have resident animals (AVMA, 2003), most commonly dogs and/or cats, making pets a common feature of the ecology of child development in the U.S. Parents identify child development benefits as the primary reason for acquiring pets (Fifield & Forsyth, 1999). There is considerable evidence that many children view family pets as social companions, and attribute to them biological processes, feelings, and cognitions (Melson, 2001).

Consistent with these perceptions are findings that some children turn to their pets for emotional support (Bryant, 1985; Collis & McNicholas, 1998). For example, in interviews with ten- to fourteen-year old Michigan youngsters who had pets available, 75% of the children indicated that when they were upset they turned to their pets (Covert, Whirren, Keith, & Nelson, 1985). When elementary school age children rated social support functions of parents, friends, and pets, the animals were seen as ties most likely to last “no matter what” and “even if you get mad at each other” (Furman, 1989). Thus, a second goal of the study was to examine children's perceptions of and behavior toward a robotic dog as a social companion. For example, we observed whether children talked to the robot dog, using questions or endearments, or affirmed that the robot dog could be a friend or could understand what the child was feeling. Developmental differences in children's use of non-humans and non-animates for social support and friendship (Bryant, 1985) suggest that younger school-age children (7–9 years) may be more likely than older children (10–15 years) to attribute sociability to a robotic dog.

Relatively little is known about children's attributions of moral standing in relation to domain or category assignment. Despite growing public awareness of animal welfare and ecology issues, research is lacking on the development of moral reasoning with regard to treatment of animals. A survey of British university students found that childhood involvement in pet care predicted more humane attitudes toward pet and non-pet animals as well as greater concern for animal welfare issues (Paul & Serpell, 1993). At a minimum, childhood experiences with animals are likely to raise moral issues of animal welfare and rights.

A content analysis of online discussion-forum postings (Friedman, Kahn, & Hagman, 2003) by AIBO owners (presumably adults) found that while 75% described the robotic dog as a technological artifact, nearly half (48%) attributed biological properties, 60% affirmed the robot's mental agency, as something that feels, thinks and is unique psychologically, and 59% saw AIBO as a social companion. These findings suggest a readiness, at least among adult AIBO owners, to ascribe biological, psychological, and social properties, if only metaphorically, to an artifact that mimics biological and psychological properties. However, in the same study only 12% of postings accorded the robotic dog moral standing, such as having rights or deserving respect. Thus a third goal of this study was to examine the extent to which children attribute moral standing (has rights, deserves respect, should not be harmed) to a robotic dog and to a living dog.

Technology innovation and diffusion are making robotic animals more accessible to children. In Japan, "robot-assisted activities" (RAA) and "robot-assisted therapy" (RAT) are used in pediatric hospitals and child clinical interventions (Yokoyama, 2001). Yet little is known about how children respond to or think about this emerging technology. A recent study by Kahn, Friedman, Perez-Granados, & Freier (2006) found that among 34- to 74-month old children who had an initial 20 min play session with a robotic dog, 46% accorded biological properties, 66% mental states, 76% social rapport, and 63% moral standing. Thus, unlike adult AIBO owners, preschoolers did not sharply distinguish between the robot's moral standing and its other properties. When Japanese and Swiss preschoolers (Yokoyama, Ribi, & Turner, 2004) interacted with a robotic dog for 5 min sessions weekly over 10 weeks, their behaviors included social bids, greetings, 'conversation,' and affectionate touch. However, there was no comparison stimulus and no measure of children's cognitions about the robot.

The present study examined children's behavior toward and understanding of a robotic dog while in its presence. This approach differs from other research assessing children's judgments of animacy and domain characteristics using photographs (Gottfried & Gelman, 2005), illustrations (Heyman, Phillips, & Gelman, 2003), or descriptions of interactions (Gelman & Williams, 1998). We believed that a child's experience with the robotic dog's repertoire of movement and actual interaction with it would increase the ecological validity of this research. In addition, using a within-participants subject design, we compared children's behavior toward and understanding of a robotic dog to an unfamiliar, friendly live dog. We believed that this comparison provides a critical line of inquiry, allowing for clearer interpretations of children's interactions with the robotic dog.

Three major research questions structured this study: First, do children behave toward a robotic dog in ways that are similar to a living dog, or more similar to a complex artifact? Based on Kahn et al. (2006), we expected to uncover evidence for both. For example, we expected that children would stroke and pet the living fur-bearing dog more than the metal robot, and would explore the robotic dog using behaviors typical of exploration of an unfamiliar artifact, such as rotating, examining and manipulating parts of the object. That said, we also expected that children would generalize to the robotic dog their repertoire of behaviors toward living dogs, such as giving directives ("Fetch, boy"), asking questions ("Do you want to play?), or motioning ("Come here"). Second, to what extent do children affirm or deny the biology, psychology, social companionship, and moral standing of a robotic dog as compared to a living dog? There is considerable evidence (see Melson, 2001, for review) that children as well as adults believe that dogs and other pets, while recognized as clearly non-human, nevertheless possess unique psychological attributes, have feelings, desires, and cognition, are capable of social companionship, and should be accorded moral standing (Beck & Katcher, 1996). Even preschoolers experience living animals as other subjectivities, with minds and emotions (Myers, 1998). We expected that most children, even the youngest in our study, would perceive marked differences between the robotic and the living dog, according the former but not the latter artifactual properties. However, based on assessments of behavior, judgments, and reasoning, the extent to which children would attribute to the robotic dog biological, psychological, social, and moral characteristics was an open question. Further, we sought to determine how children justified their attributions about the robotic dog's characteristics. Third, are there age group differences in children's behaviors and understandings? Based on limited prior research (Bryant, 1985; Furman, 1989), we expected that children in the youngest age group (7–9 year olds) would treat the robotic dog as more of a social companion than would older children. We did not expect age group differences in children's cognitions about the biology or psychology of the robotic dog, given the establishment of causal–explanatory reasoning systems for naive biology, physics and biology by age seven (Wellman, Hickling, & Schult, 2000). We made no prediction with respect to cognitions about moral standing, in the absence of relevant research or theory.

2. Method

2.1. Participants

Seventy-two children from three age groups (7–9 years; 10–12 years; and 13–15 years) evenly divided by sex, participated in this study. Children were recruited from area public schools and by television, radio, and print advertising. Most children came from married, middle-class families (86% had at least one parent who had completed 4 years of college, and 72% had family incomes over $50,000 per year) in a small Midwestern city and its surrounding suburban and rural areas. Almost all families had pets: 87% had at least one pet at the time of the study, and all but 2 families had a history of pet-keeping. Dogs were the most common pet, with 89% of pet owners having at least one dog. None of the participating children owned or had played with AIBO previously, although 37% owned some type of simple "robotic pet," such as Technodog or Furby. All the children were regularly using a computer either at home or in school and usually in both.

2.2. Materials, procedures and measures

2.2.1. Target dogs

The robotic dog used in the study was Sony's 210 AIBO, the most advanced robotic 'animal' available at the time of the study. AIBO was designed to be an "autonomous robot" dog. It has a dog-like metallic form, moveable body parts, and sensors that can detect distance, acceleration, vibration, sound, and pressure. As one of its compelling activities, AIBO can locate a pink ball through its image sensor, walk toward the pink ball, kick it, and head butt it. It is also capable of “learning.” For example, to increase the tendency for AIBO to behave in a particular way, one gently touches or pets AIBO's head sensor after the desired behavior; conversely, to decrease the tendency for AIBO to behave in a particular way, one sharply taps the same sensor after the undesirable behavior. Thus different AIBOs come to have slightly different behavioral repertoires (“personalities”). In somewhat unpredictable patterns, not unlike a live dog, AIBO will shake itself, sit down, lie down, stand up, walk, and rest. AIBO also initiates interactions with humans, such as offering its paw; and it may respond with “pleasure” (green lights) or “displeasure” (red lights) after certain forms of interaction (such as shaking its paw or not). Thus, not only can AIBO initiate dog-like action, but AIBO can modify its subsequent behavior based on the human response to its initiated action.

The live dog, referred to as Canis, was one of two Australian Shepherd females, a mother and her daughter. It was difficult to tell the two dogs apart from one another in looks and behavior. These dogs were Delta Society certified to serve in animal-assisted activities (AAA) involving children.

2.2.2. Session format

Each child participated in two individual sessions, one with the robotic dog and one with the live dog, each approximately 45 min long. Order of sessions was counter-balanced. Each session began with a five minute unstructured play period with the target dog and a pink plastic ball. A 38-question interview followed, with the child free to continue to play with the target dog. Following the second session, the interviewer conducted a card sort task after removing the target dog. Both sessions plus the card sort task were videotaped from behind a one-way mirror. The child wore a wireless microphone, and a supplemental conference microphone in the room recorded all audio.

2.2.3. Interview protocol

During the interview portion of each session, the child responded to a series of questions assessing the child's perceptions of the target dog in four domains: (a) biological entity (6 questions); (b) mental states (10 questions); (c) social companion (15 questions); and (d) moral standing (6 questions). (See Table 1 for complete set of questions.) Questions were selected based on a review of

Table 1
Interview protocol (X = robot dog, live dog)

Domain	Question
Biological entity	Does X have a stomach?
	Does X eat?
	Does X go to the bathroom? (pee or poop)
	Can X get sick?
	Can X die?
	Can X have babies?
Mental states	Can X feel happy?
	Can X feel embarrassed?
	Can X see the ball?
	Can X see you?
	Can X hear you?
	Does X understand you?
	If you saw X again, would X recognize you?
	Does X know how you are feeling?
	Would you talk to X?
	Would you confide in X?
Social companion	Do you like X?
	Does X like you?
	Can X like anyone X wants?
	Can X be your friend?
	Can you be a friend to X?
	If you were sad, would you feel better with X?
	If X were sad, would X feel better with you?
	Can you play with X?
	Can X play with you?
	If a friend came over and you were playing with your friend, would X feel left out?
	If a friend were playing with X, would you feel left out?
	If you were going to sleep, would you want to cuddle with X?
	If X were going to sleep, would X want to cuddle with you?
	If you were home alone, would you feel better with X?
	If X were home alone, would X feel better with you?
Moral standing	If X were whimpering (making noise) would it be OK or not OK to ignore X?
	If X's leg breaks, is it OK or not OK to not fix it right away?
	If you decided you did not like X anymore, is it OK or not OK to give X away?
	If you decided you did not like X anymore, is it OK or not OK to throw X in the garbage?
	If you decided you did not like X anymore, is it OK or not OK to destroy X?
	Is it OK or not OK to hit X?

literature yielding key prompts to assess biological and psychological attributes (Gelman & Williams, 1998; Inagaki & Hatano, 2002). For the social companionship and moral standing domains, questions were derived from a literature review of children's relationships with animals (Beck & Katcher, 1996; Kahn, 1999; Melson, 2001).

Each question asked the child to affirm or deny some characteristic of the target dog. For *biological entity*, each question asked about a biological process or feature (e.g., "Does X eat?" For *mental states*, each question asked about a psychological state (e.g., "Can X feel embarrassed?"), a sensory capacity (e.g., "Can X hear you?"), or a cognitive understanding (e.g., "Can X understand you?). Two questions in this domain asked about the child's readiness to communicate with the target dog: "Would you talk to X?" and "Would you tell secrets to X?" For *social companion*, questions were of two types: X as a social companion to the child, for example, "Can X be your friend?" (8 questions), and the child as a social companion to X, for example, "Can you be a friend to X?" (7 questions). For *moral standing*, six questions asked the child if it was OK or not OK to engage in a series of actions (from less to more severe) that would harm X. Note that the affirmative answer, "OK," indicates *lack of* moral standing. Order of domain was counterbalanced across participants, but within domain the order of questions was fixed. Pilot testing suggested an optimal within-domain question order that avoided repetition and encouraged the child to elaborate his or her thinking through follow-up questions. For example, in the moral standing domain, questions progressed from less to more severe harmful actions against the target dog.

2.2.4. Card sort task

The interviewer presented a laminated color 4"×6" photograph of AIBO that served as an anchor. Then all pair-wise comparisons of color photographs of a humanoid robot, live dog, stuffed dog, and desktop computer were presented in random order: robot/live dog; robot/stuffed dog; robot/desktop computer; desktop computer/live dog; desktop computer/stuffed dog; and stuffed dog/live dog. For each pair, the child was asked, "Is AIBO more like (object) A or more like (object) B?"

2.3. Coding

Children's behaviors toward the target were coded from the videotaped play portion of each session, i.e. the first 5 min. Children's interview and card sort responses were coded from transcripts of each session derived from both the videotapes and audiotapes.

2.3.1. Behaviors

Based on an inductively developed ethogram (Montagner et al., 1988) of children's behaviors toward the target dog, three types of social behaviors were coded: social touch (gentle pats, petting, scratching, kissing, hugging), verbal engagement (greetings, general verbalizations), and attempts at reciprocity, both verbal (asking questions, commanding) and nonverbal (motioning, offering the ball, presenting one's hand; see Table 2). In addition, we coded the child's exploration of the target dog (for example, poking in an effort to determine how the target moved) and proximity to the target dog, defined as being within the child's arm

Table 2
Frequency of children's behavioral interactions toward robot dog and live dog

Behavior	Robot dog (*N*=72)						Live dog (*N*=72)						Sign test *p*-value
	Total occurrences	Median	Range		At least once		Total occurrences	Median	Range		At least once		
			Min	Max	*n*	%			Min	Max	*n*	%	
Exploration as artifact	254	2	0	18	43	60%	37	0	0	5	17	24%	<.0005*
Proximity	47	0	0	5	26	36%	73	0	0	9	32	44%	.617
Social touch	276	2	0	22	45	63%	1074	13	2	39	72	100%	<.0005*
General	48	0	0	6	15	21%	54	0	0	12	27	38%	.216
Petting	168	0	0	17	33	46%	670	8	0	24	71	99%	<.0005*
Scratching	29	0	0	7	12	17%	317	4	0	21	53	73%	<.0005*
Kissing	1	0	0	1	1	1%	5	0	0	2	4	6%	.375
Hug	1	0	0	1	1	1%	8	0	0	5	3	4%	.625
Mistreatment	6	0	0	3	3	4%	8	0	0	3	4	6%	1.000
Verbal engagement	397	2	0	33	59	82%	534	7	0	26	62	86%	.200
Salutation	77	0	0	7	33	46%	85	1	0	11	44	61%	.775
General	263	1	0	31	45	63%	379	3	0	24	56	78%	.001*
Attempts at reciprocity	1267	14	0	68	69	96%	924	9	0	65	69	96%	.002*
Motioning	189	1	0	28	43	60%	149	1	0	13	39	54%	.341
Directives	301	2.5	0	22	48	67%	248	1	0	20	44	61%	.127
Questioning	164	0	0	19	32	44%	244	2	0	23	50	69%	.010
Ball offering	558	7	0	31	64	89%	240	2	0	27	58	80%	<.0005*
Hand presentation	55	0	0	5	29	40%	43	0	0	4	23	32%	.499
Apprehension	26	0	0	6	13	18%	8	0	0	5	4	6%	.006

Note. When the totals for higher level categories are higher than the sum of the totals for the subcategories, behaviors were coded at the higher level or other subcategories have been omitted.
*Statistically significant difference after adjusting for multiple comparisons using Holm's sequential Bonferroni method with family significance level .05.

reach. Finally, because children were interacting with a novel object (robot dog) or unfamiliar dog, we coded any apprehensive behaviors, such as startle responses, withdrawal, or fear expressions. The onset and offset of each behavior of interest were recorded; an instance was defined as offset equal to or greater than 2 s. To establish reliability, a second coder independently coded a randomly selected 20% (14 participants) of all videotapes to a criterion of 80% agreement as defined by Cohen's kappa = .80.

2.3.2. Verbal responses

Two types of questions were asked during the interview. Affirmation/negation questions asked the child to respond "yes" or "no" ("OK" or "not OK" for moral standing questions, coded inversely). Each of these questions was coded as an affirmation ("yes", "not OK") or a negation ("no", "OK") of the property in question. In some instances, children gave mixed responses because they had difficulty deciding on a response or offered qualifications. For example, in answer to the question, "Does AIBO have a stomach?" one child said: "In one sense yes, in another no." Because such mixed responses were rare, accounting for approximately 4% of all responses, and the number of mixed responses did not differ by target dog, they were not counted in the analyses, which only looked at affirmative responses. The measure for the affirmation of properties was the proportion of affirmative responses within each domain for each individual. Again, note that for the domain, *moral standing*, agreement that a harmful action is "OK" denies moral standing, while belief that a harmful action is "not OK" affirms moral standing.

The second type of verbal response was an open-ended follow-up question ("Why?"; "How do you know that?"; "Why do you think/not think so?") to each affirmation/negation question. The purpose of the follow-up question was to prompt the child for justification of the preceding response. This produced 6 justification responses for biological entity, 10 for mental states, 15 for social companion, and 6 for moral standing. Each justification response was coded from transcripts (and original audio- or videotape as needed). Drawing on Kahn, Friedman, Freier, and Severson (2003), a coding manual was developed that assigned each thought unit (a meaningful phrase or sentence expressing a distinct form of reasoning) to one or more of the following forms of justification in terms of category membership, attributes, or processes: artifact, biological entity, "qualified" biological entity (e.g., "He [AIBO] doesn't *really* have eyes") psychological entity, social companion, moral entity, and analogical reasoning as like a human or animal. For example, when asked to justify a "no" response to "Does AIBO have a stomach?" responses included "He's just a robot" (justifies as artifact), "He's not a real dog" (justifies as not a biological entity); "He has kind of a metal stomach but it isn't real" (justifies using qualified biological reality). As another example, when asked to justify a "not OK" response to the question, "Is it OK or not OK to hit AIBO?" one child explained "AIBO would feel bad" (justifies as psychological entity). Although some children offered multiple justifications for a single affirmation or negation, we analyzed only the first justification offered in each response. Affirmation/negation coding and justification coding were conducted independently by two different teams of coders. In both cases, a randomly selected 20% of transcripts ($n = 14$) were double-coded to a criterion reliability of Cohen's kappas ≥ .80.

3. Results

3.1. Preliminary analyses

To test for socioeconomic differences, two groups, those parents reporting under $50,000 yearly income (28%) and those reporting over $50,000 yearly income (72%), were compared. A Mann–Whitney U test was used to test for differences in behavior between the two groups. Only 1 comparison out of 38 tests was significant, $p = .049$. When Holm's sequential Bonferroni method was used to reduce Type I error, there were no significant differences for socioeconomic status based on income. Similarly, Mann–Whitney U tests with Holm's sequential Bonferroni correction indicated no sex differences (1 out of 38 comparisons with $p < .05$). The Kruskal–Wallis test was used to test for differences in behavior counts across the three age groups. Only 2/38 yielded p-values < .05. Adjustment for multiple comparisons indicated no statistically significant differences based on age group. Therefore, SES, age group and sex were not included in subsequent analyses of the behavioral data.

Because both the living dogs and the robotic dog may change their behaviors over time and in response to interactions with participating children, we randomly selected three sessions from the initial 10 conducted and another three from the last 10 sessions conducted and compared behaviors and cognitions. There were no significant differences based on session history (early versus late).

3.2. Behaviors

Table 2 presents the total number of instances of each child behavior for the entire sample, the median and range of the number of instances per child, and the number and percent of children exhibiting at least one instance of each behavior. The sign test was used to compare the median number of occurrences of a behavior with the robot dog to those with the living dog (see Table 2). Asterisks indicate statistically significant findings after adjusting for multiple comparisons using Holm's sequential Bonferroni method with family significance level .05.

As expected, children explored the robot dog as an artifact more frequently than they did the living dog. In contrast, children used social touch, particularly petting and scratching, more with the living dog than with the robot dog. Median frequency of social touch behaviors was more than six times as high with the living versus the robot dog. Although 63% of the children spoke to the robot at least once, the frequency of social speech was higher with the living dog ($Mdn = 3$ occurrences per child) than with the robot ($Mdn = 1$). Virtually all children (96%) attempted to engage both dogs in interaction using social movements, especially 'offering' the ball, but children offered the ball significantly more frequently to the robot dog (*Mdn*=7 occurrences per child) than to the live dog (*Mdn*=2). However, attempts at verbal engagement were more likely with the live dog; 69% of children asked the live dog a question at least once, whereas 44% asked the robot a question ($p<.0005$, McNemar test).

3.3. Verbal responses

Table 3 shows the median, mean and standard deviation of the proportion of affirmations for each subject for the robot dog and the live dog. The table also reports the value of Cronbach's alpha, a measure of the internal consistency of the questions within each domain. For the robot dog, the values of alpha are at least .70 for all four domains. For the live dog the values of alpha are lower due to the fact that (as expected, particularly in the biological domain) many items yielded 100% affirmation. The lack of variability in responses results in zero correlation between these items and all other items in the scale, suppressing the value of alpha.

As expected, matched pairs *t*-tests showed that children consistently affirmed the biology, psychology, social companionship and moral standing of the live dog more than the robot. However, on average, when questioned about the robot dog, children affirmed 70% of the questions about social companionship and 76% of those on moral standing, indicating that the robot was seen as providing social companionship and deserving of moral treatment, although not to the extent of the living dog.

Two-way ANOVAs tested for age and sex differences in children's affirmations. Separate analyses were conducted for responses to the robot and to the live dog. There were no significant age group or sex differences for responses about the live dog. For the robot dog, there were no sex differences, but there were significant age group differences in social companionship ($p<.0005$) and moral standing ($p<.05$). For social companionship questions, 7–9 year olds affirmed 82% of the questions, as compared with 71% of the 10–12 year olds and 55% of the 13–15 year olds. Similarly, for the moral standing questions, the mean percentage of affirmations for the youngest group was 86%, 76% for the 10–12 year olds, and 64% for the oldest group. Although it was not statistically significant ($p=.076$), a similar pattern occurred for biological properties of the robot: 26% for 7–9 year olds, 26% for 10–12 year olds, and 14% for 13–15 year olds.

Because significant age group differences occurred only for those domains with some (social companionship) or all (moral standing) syntactically complex sentences (i.e., containing dependent clauses), we considered the possibility that children might be responding to questions of simple versus complex syntactical structure differently. In the social companionship domain, we separated the 15 social companionship questions into those with simple ($n=7$) and complex ($n=8$) syntactic structure. On average, children affirmed 76% of simple syntax questions (e.g., "Do you like AIBO?") as compared to 56% of more complex syntax questions. When Age group × Sex ANOVAs were computed for each type of question, age group differences remained for the complex syntax questions ($p<.0005$), but not the simple syntax questions ($p>.06$). For the complex syntax questions, 77% were affirmed by 7–9; 59% by 10–12 year olds and 38% by 13–15 year olds. Within the moral standing domain, all six questions had dependent clauses and hence, were considered syntactically complex. Three of the six questions had the same hypothetical as dependent clause ("If you decided you did not like AIBO anymore…"). For one question ("Is it OK or not OK to give AIBO away?") 40% of children said it was "not OK." For the other two questions ("Is it OK or not OK to throw AIBO in the garbage?" and "Is it OK or not OK to destroy AIBO?") 82% and 85% of the children responded "not OK." (The pattern of results did not differ by age group). This indicates that on average, children were responding differently to questions of similar syntactic complexity within the moral standing domain.

Overall, the analyses based on syntactic complexity of questions suggest that question syntax did not prompt an overall "yes" response bias for the sample as a whole, or for the youngest age group. However, age group differences related to social companionship question syntax should prompt caution in interpreting age group differences.

Table 4 summarizes the justification responses, showing the median and range of the number of times each justification category was used per child, the number and percentage of children who used a particular category at least once, and the total number of times the justification category was used across all children. The sign test was used to compare the medians of the distributions for the robot and for the live dog. All *p*-values<.05 remained significant after applying Holm's sequential Bonferroni method.

In general, children justified their prior affirmations ("yes," "not OK") or negations ("no," "OK") by pointing out what the robot or live dog possessed rather than describing what the target dog lacked or was not. All but one child justified their affirmations or negations at least once by explaining that the robot was an artifact or possessed artifactual properties, and they tended to use this justification category quite frequently with the robot (*Mdn*=10.5 occurrences per child), but very rarely with the live dog (*Mdn*=0

Table 3
Proportion of affirmations for live dog and robot dog by domain

	Proportion of affirmation								Matched pairs *t*-test *p*-value
	Live dog (*N*=72)				Robot dog (*N*=72)				
	Median	Mean	*SD*	Alpha	Median	Mean	*SD*	Alpha	
Biological attributes (6 questions)	1.000	.992	.034	.00	.143	.220	.221	.70	<.0005*
Mental states (10 questions)	.882	.836	.132	.43	.600	.562	.260	.73	<.0005*
Social companionship (15 questions)	.933	.914	.103	.62	.786	.700	.256	.89	<.0005*
Moral standing (6 questions)	.833	.863	.120	.09	.833	.757	.280	.79	.001*

Note: Cronbach's alpha is a measure of the internal consistency of a scale.
*$p<.05$.

Table 4
Frequency of use of justification categories for the robot dog and live dog

Justification category	Robot dog ($N=72$)						Live dog ($N=72$)						Sign test p-value
	Median	Range		At least once		Total uses	Median	Range		At least once		Total uses	
		min	max	n	%			min	max	n	%		
Affirms as artifact	10.5	0	30	71	99%	804	0	0	6	11	15%	17	<.0005*
Negates as artifact	0	0	6	7	10%	15	0	0	2	7	10%	8	1.000
Affirms biology	4	0	14	71	99%	330	11	3	19	72	100%	791	<.0005*
Negates biology	3	0	15	64	89%	321	0	0	4	26	36%	38	<.0005*
Qualified biological reality	1	0	7	42	58%	79	0	0	4	2	3%	5	<.0005*
Affirms mental states	6	0	20	68	94%	443	11	2	19	72	100%	730	<.0005*
Negates mental states	3	0	20	65	90%	307	1	0	9	62	86%	143	<.0005*
Affirms social companionship	4	0	11	64	89%	278	4.5	1	12	72	100%	386	.078
Negates social companionship	0	0	5	33	46%	55	0.5	0	2	36	50%	47	.511
Affirms moral standing	4	0	9	66	92%	286	6	0	11	71	99%	450	<.0005*
Negates moral standing	0	0	2	14	19%	18	0	0	1	9	13%	9	.383
Analogical reasoning	2	0	13	59	82%	180	5	0	16	70	97%	411	<.0005*

occurrences per child, with only 15% ever using the category). All or virtually all children mentioned at least once that the live dog was a biological entity (or possessed biological properties), had mental and emotional properties, was a social companion, and had moral standing. While these results were expected, the overwhelming majority of children also at least once justified their prior judgments in terms of the robot's biology (99%), mental states (94%), social companionship (89%) and moral standing (92%). Although most children did use each of these justification categories at least once with the robot dog, the sign-test indicated that they employed reasoning based on affirming biology (*Mdn*=11 live dog; *Mdn*=4 robot), mental states (*Mdn*=11 live dog; *Mdn*=6 robot), and moral standing (*Mdn*=6 live dog; *Mdn*=4 robot) more frequently across the interview with the live dog than the robot dog. Children also drew more frequently on analogies to other living animals and to humans with the live dog (*Mdn*=5) than with the robotic dog (*Mdn*=2). However, there were no significant differences between dog type with respect to the frequency of use of justifications based on social companionship.

3.4. Card sort task

Binomial tests showed that children viewed AIBO as more like a robot than a desktop computer (87%), a stuffed dog (90%) or a real dog (74%). Children also saw AIBO as more like a desktop computer than a stuffed dog (74%). All these comparisons were significant, $p<.0001$. Children were more closely divided on whether AIBO was more like a desktop computer than a real dog (46%) or more like a real dog than a stuffed dog (58%). Binary logistic regression modeled the probability of getting each comparison choice as a function of age, sex, and age × sex. Boys were more likely (71%) than girls (46%) to say that AIBO was more like a real than a stuffed dog ($p=.02$).

4. Discussion

The behavioral and interview results provide some evidence that children from seven- to fifteen-years old distinguish a robot dog from a living dog. In the unstructured play period, the majority of children explored the robot as an artifact, poking and touching AIBO as they would an unfamiliar toy. Only 24% of the children ever touched the live dog in this way and they did so infrequently. Children much less frequently engaged in gentle, affectionate social touch, particularly petting or scratching with the robotic dog when compared with the living dog. Across the many interview questions, children consistently affirmed the biology, psychology, companionship, and moral standing of the living dog more than of the robotic dog. In justifying these affirmations, children drew on reasoning that the robot belonged predominantly to the category of “artifact,” possessing artifactual properties and processes, while the live dog belonged to the category of biological entity and mental agent. In addition, children drew on analogies to other living animals and to humans more frequently when explaining responses about the living dog vs. the robot dog. Finally, the card sort data provides added support that AIBO is viewed more like a robot than a living dog or even a stuffed one.

The multiple methods employed in this study yielded a more complex picture of children‘s engagement with a social robot than would either behavioral assessment or cognitive constructions alone. For example, while children generally recognized that AIBO was not animate, they behaviorally treated the robotic pet “as if” it were animate, by attempting reciprocal play, and verbally engaging the robot.

When one compares responses toward a robotic pet with those directed at a living dog, the hope of marketers and animal rights activists that social robots such as AIBO might be a substitute for a living dog as a pet seems misguided, or at least, given current technological capabilities, premature. Rather, one might conclude that the robot dog is being assimilated to children's cognitive models of a mechanical or computer-based toy. Even their apparent attributions of biology, for example, that AIBO can “die” or “get sick,” were often justified by children's familiarity with the application of biological terms (e.g., viruses) to computers.

However, the results also show that children were engaging with the robot dog as an interactive partner. Over 80% of the children spoke to the robot and gave commands as frequently to the robot as the living dog. Children used motions and ball offering to engage the robot in play. When one considers AIBO's hard metal surface, it is notable that 46% of children gently petted the robot at least once. Moreover, the interview data show that most of children's responses (over 60%) toward the robot dog affirmed its psychological and emotional states, companionship qualities, and moral standing, even while failing to affirm that the robot possessed a biology (22%). Put another way, children accorded the robot dog many of the core attributes of a minded animate while at the same time, denying its animacy.

Given that children as young as 3 years of age acquire an accurate animate–inanimate distinction and by 5 years of age, a living–nonliving distinction (Carey, 1985; Inagaki & Hatano, 2002), it is not surprising that clear and marked differences in attributions of biology would be found. Nonetheless, these children were surprisingly willing to treat the robot dog as "dog like." As Kahn et al. (2006) suggest, such findings may be evidence of the emergence of a new ontological category, neither artifact nor living being. A more modest claim might be to interpret the results as reflecting a new "non-core domain" (Gelman & Williams, 1998) or emerging conceptual structure about social robots. As Gelman and Williams (1998) note, knowledge acquisition in such domains is influenced by the way inputs map on to previously acquired core domains. Thus, the fact that AIBO is in some ways like a real dog may lead children to assimilate their constructs about it to the core domain of animal.

In the future, as social robots become more interactive and as their forms more closely emulate biology, they may increasingly be treated "as if" they were living beings. The readiness of children in this study to do so is striking, given how crudely AIBO approximates dog behavior and features (e.g., musical notes instead of dog-like barks). Perhaps most children, particularly pet owners, have such well established "scripts" for relating to a living dog, that they readily apply them to even a rough robot analogue. Another possibility, suggested by Turkle (1995), is that "evocative objects" such as robotic pets, which are both interactive and opaque (i.e., their inner workings are not visible), encourage the child or adult to treat them in psychological terms, as having intentionality and personality. To the extent that such robots reflect design based on artificial life, they mimic critical features of biological systems, specifically adaptation, autonomous behavior, and emergent properties (Korienek & Uzgalis, 2002). Finally, Turkle (1995) notes a tendency among both children and adults to treat computer artifacts that are minimally responsive as more intelligent than they really are: "Very small amounts of interactivity cause us to project our own complexity onto the undeserving object" (p. 101). In fact, the pet rock and Tamagotchi phenomena of past years suggest that interactivity, when entirely absent, can be readily projected even on stones and small plastic spheres.

Of particular interest in this study were children's attributions of moral standing (or lack thereof) to AIBO. As expected, there was near universal agreement that the living dog was entitled to be free from harm. Kahn (2002) has suggested that biocentric reasoning – the view that the natural environment has moral standing apart from its use as a commodity for humans – may partly develop in children through a process of, what he calls, "isomorphic biocentric reasoning," whereby children recognize a correspondence between humans and animals. Given the well documented attachment children have for their companion animals and the pervasive view that pets are members of their human family of owners (Melson, 2001), we expected that children would extend biocentric reasoning to living dogs, including unfamiliar ones owned by others. Nor is it surprising that a robotic dog, viewed as a non-biological entity, would be less likely than a living dog to be seen as deserving moral regard. However, in contrast to the Kahn et al. (2003) analysis of adult AIBO owners' perceptions, most of the children did accord moral standing to the robot dog. For example, children were no more likely to feel that it was OK to hit the robot dog than to hit the living dog. Rather, the proportion of responses affirming moral standing was similar to that found in the Kahn et al. (2006) study of preschoolers.

To the extent that a robotic dog mimics or even approximately suggests a living dog, children may extend their moral regard for their own pets or other dogs to the robot, at least partially. Following Gentner and Namy's (1999) account of analogical reasoning, children may have mapped the structure of moral regard for living dogs on to the analogous robot dog. However, one should note that the study did not formally assess analogical reasoning; rather, justifications that AIBO "was" or "was like" a real dog, animal, or human were coded as analogical reasoning. Future research might focus more directly on the question of analogical reasoning from animates to technological emulations of life forms.

The significant age group effects found for affirmations of both moral standing and social companionship should be interpreted with caution. They may suggest that as children age, they become less likely to apply companionship and moral standing. This is consistent with other results on the development of naïve biology and psychology that children first generalize from themselves and other humans in making attributions of biological and psychological processes to unfamiliar objects (Carey, 1985; Inagaki & Hatano, 2002). To the extent that the child views the object as "like me" or like a human, the child may more readily extend to the object social companionship and moral claims. However, because questions in the moral standing and social companionship domains contained more syntactically complex questions, the age group differences might be an artifact of question structure.

A limited first-time interaction with an unfamiliar robotic dog yields a child's first impression, which might change with more experience. However, Yokoyama et al. (2004) found that the behavior of Japanese and Swiss preschoolers after 10 weeks of weekly sessions with AIBO could be predicted from behavior during the initial five minute session. Thus, it is unclear how a child's interaction history with a robotic pet or experience as an 'owner' might affect behavior or understanding. Although socioeconomic status and sex were not associated with behavior or verbal responses, other individual or family variables may be worthy of investigation. The participants in the present study were relatively homogeneous with respect to ethnicity, religion, and geographical area. Moreover, as virtually all the participants currently or formerly owned pets, most of which were dogs, it was not possible to examine the effects of pet ownership on behavior or cognition. It is possible, however, that children who are more deeply attached to their dogs respond to a robotic pet differently than children who are not dog owners or who have a less intense attachment. Similarly, because all participants regularly used computers, we could not assess the relation between computer use and behavior toward or cognitions about a robotic pet. In general, child and family characteristics may predict different responses to social robots. For example, lonely adults, compared to their non-lonely peers, make more positive social responses to a social robot (Lee, Jung, Kim, & Kim, 2006), although this research has not extended to children.

Cultural differences remain unexplored as well. It is possible that in cultures where dog ownership rates are relatively low (compared with the U.S.) and dogs are considered less suitable as pets than other species, such as goldfish, children may respond to robotic dogs less positively and judge them to have fewer psychological, social, or moral characteristics than the sample studied in this paper. However, in the limited studies of Japanese children (Yokoyama, 2001; Yokoyama et al., 2004), rates of positive behavior (cognitions were not assessed) did not differ significantly from those reported in this U.S. sample. Moreover, Japanese hospitals and clinics are rapidly incorporating robotic dogs and other 'pets' for their purported benefits in distracting and soothing children.

The results of this study point up both the promise and limits of robotic assisted therapy (RAA). To the extent that children respond to a social robot as a minded social being, it holds promise for some conditions, such as autism, where children do not respond well to other humans or living animals, or for highly aggressive children, where animal welfare concerns may preclude therapy with living animals. However, the adaptive and interactive capacities of social robots remain limited when compared to their animate counterparts. Developmentalists, clinicians and robot designers need dialogue and collaborative research so that social robots can better serve therapeutic and companionship needs. In future research, children might be asked directly about the features of social robots that would make them better companions.

The computer revolution is transforming children's sense of themselves, others, and their environment. As Bynum and Moor (2000) note: "To miss the moral dimensions of the computer revolution is to miss the importance of the revolution…The growing information revolution is not 'merely technological'—it is *fundamentally social and ethical*" (p. 5). As part of children's environment, social robots will continue to proliferate, and will form a part of an increasingly personified computational world (e.g., cars will likely come to have voice interfaces by which it interacts with its occupants). This study points to the possibility that children will construct new conceptual categories for such personified computation, or at a minimum apply to such computation in new ways their existing biological, mental, social, and moral categories.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. IIS-0102558. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

AVMA (2003). *The veterinary service market for companion animals.* Schaumburg, IL: Center for Information Management.

Beck, A., & Katcher, A. H. (1996). *Between pets and people.* West Lafayette, IN: Purdue University Press.

Breazeal, C. (2003). Toward social robots. *Robotics and Autonomous Systems*, *42*, 167–175.

Bryant, B. (1985). The neighborhood walk: Sources of support in middle childhood. *Monographs of the Society for Research in Child Development*, *50*, 1–114.

Bynum, T. W., & Moor, J. H. (2000). How computers are changing philosophy. In T. W. Bynum & J. H. Moor (Eds.), *The digital phoenix: How computers are changing philosophy* (pp. 1–14). Oxford: Blackwell.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Collis, G., & McNicholas, J. (1998). A theoretical basis for health benefits of pet ownership: Attachment versus psychological support. In C. C. Wilson & D. C. Turner (Eds.), *Companion animals in human health* Thousand Oaks, CA: Sage.

Covert, A. M., Whirren, A. P., Keith, J., & Nelson, C. (1985). Pets, early adolescents and families. *Marriage and Family Review*, *8*, 95–108.

Fifield, S. J., & Forsyth, D. K. (1999). A pet for the children: Factors related to family pet ownership. *Anthrozoos*, *12*, 24–32.

Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and Autonomous Systems*, *42*, 143–166.

Friedman, B., Kahn, P. H., Jr., & Hagman, J. (2003). Hardware companions?: What online AIBO discussion forums reveal about the human–robotic relationship. *Proceedings of the Conference on Human Factors in Computing Systems* (pp. 273–280). NY: Association for Computing Machinery Press.

Furman, W. (1989). The development of children's social networks. In D. Belle (Ed.), *Children's social networks and social supports* (pp. 151–172). NY: Wiley.

Gelman, S. A. (2004). Psychological essentialism in children. *Trends in Cognitive Sciences*, *8*, 404–409.

Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: Not by motion alone. In D. Sperber, D. Premack, & A. J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 150–184). Oxford: Clarendon Press.

Gelman, S. A., & Gottfried, G. M. (1996). Children's causal explanations for animate and inanimate motion. *Child Development*, *67*, 1970–1987.

Gelman, R., & Williams, E.M. (1998). Enabling constraints for cognitive development and learning: Domain specificity and epigenesis. In W. Damon (Series Ed.) & D. Kuhn, & R. S. Siegler (Vol. Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception and language* (5th ed., pp. 575–630). NY: Wiley.

Gentner, D. (1989). The mechanisms of analogical reasoning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199–241). Cambridge: Cambridge University Press.

Gentner, D. (2005). The development of relational categorical knowledge. In L. Gershkoff-Stowe & D. Rakison (Eds.), *Building object categories in developmental time* (pp. 245–275). Mahwah, NJ: Erlbaum.

Gentner, D., & Namy, L. (1999). Comparison in the development of categories. *Cognitive Development*, *14*, 487–513.

Goswami, U. (2001). Analogical reasoning in children. In D. Gentner, K. J. Holyoak, & B. N. Kokinov (Eds.), *The analogical mind* (pp. 437–470). Cambridge, MA: MIT Press.

Gottfried, G. M., & Gelman, S. A. (2005). Developing domain-specific causal–explanatory frameworks: The role of insides and immanence. *Cognitive Development*, *20*, 137–158.

Heyman, G. D., Phillips, A. T., & Gelman, S. A. (2003). Children's reasoning about physics within and across ontological kinds. *Cognition*, *89*, 43–61.

Inagaki, K. (1997). Emerging distinctions between naïve biology and naïve psychology. In H. M. Wellman & K. Inagaki (Eds.), *The emergence of core domains of thought: Children's reasoning about physical, psychological and biological phenomena.New directions for child development*, *Vol. 75*. (pp. 27–44) San Francisco: Jossey-Bass.

Inagaki, K., & Hatano, G. (1996). Young children's recognition of commonalities between animals and plants. *Child Development*, *67*, 2823–2840.

Inagaki, K., & Hatano, G. (2002). *Young children's naïve thinking about the biological world.* NY: Psychology Press.

Kahn, P. H., Jr. (1999). *The human relationship with nature: Development and culture.* Cambridge, MA: MIT Press.

Kahn, P. H., Jr. (2002). Children's affiliations with nature: Structure, development, and the problem of environmental generational amnesia. In P. H. Kahn Jr. & S. R. Kellert (Eds.), *children and nature: Psychological, sociocultural, and evolutionary investigations* (pp. 93–116). Cambridge, MA: MIT Press.

Kahn, P. H., Jr., Freier, N. G., Friedman, B., Severson, R. L., & Feldman, E. (2004). Social and moral relationships with robotic others? *Proceedings of the 13th international workshop on robot and human interactive communication* (pp. 545−550). Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE).

Kahn, P. H., Jr., Friedman, B., Freier, N., & Severson, R. (2003). *Coding manual for children's interactions with AIBO, the robotic dog — The preschool study (UW CSE Technical Report 03-04-03).*Seattle: University of Washington, Department of Computer Science and Engineering Available online at: ftp://ftp.cs.washington.edu/tr/2003/04/UW-CSE-03-04-03.pdf

Kahn, P. H., Jr., Friedman, B., Perez-Granados, D. R., & Freier, N. G. (2006). Robotic pets in the lives of preschool children. *Interaction Studies: Social Behavior and Communication in Biological and Artificial Systems*, *7*, 405−436.

Korienek, G., & Uzgalis, W. (2002). Adaptable robots. In J. H. Moor & T. W. Bynum (Eds.), *Cyberphilosophy: The intersection of computing and philosophy* (pp. 78−92). Oxford: Blackwell.

Lee, K. M., Jung, Y., Kim, J., & Kim, S. R. (2006). Are physically embodied agents better than disembodied social agents?: The effects of physical embodiment, tactile interaction, and people's loneliness in human–robot interaction. *International Journal of Human–Computer Studies*, *64*, 962−973.

Melson, G. F. (2001). *Why the wild things are: Animals in the lives of children.* Cambridge, MA: Harvard University Press.

Montagner, H., Restoin, A., Rodriguez, D., Ullmann, V., Viala, M., Laurent, D., et al. (1988). Social interactions of young children with peers and their modifications in relation to environmental factors. In M. R. A. Chance & D. R. Omark (Eds.), *Social fabrics of the mind* (pp. 237−259). Hillsdale, NJ: Erlbaum.

Myers, G. (1998). *Children and animals: Social development and our connections to other species.* Boulder, CO: Westview Press.

Opfer, J. E. (2002). Identifying living and sentient kinds from dynamic information: The case of goal-directed versus aimless autonomous movement in conceptual change. *Cognition*, *86*, 97−122.

Paul, E. S., & Serpell, J. (1993). Childhood petkeeping and humane attitudes in young adulthood. *Animal Welfare*, *2*, 321−337.

Rakison, D. H., & Poulin-Dubois, D. (2001). Developmental origin of the animate–inanimate distinction. *Psychological Bulletin*, *127*, 209−228.

Reeves, B., & Nass, C. (1998). *The media equation. How people treat computers, television, and new media like real people and places*. NY and Stanford, CA: Cambridge University Press and Center for the Study of Language and Information Publications.

Scholl, B. J., & Tremoulet, P. D. (2000). Perceptual causality and animacy. *Trends in Cognitive Science*, *4*, 299−309.

Turkle, S. (1995). *Life on the screen: Identity in the age of the internet.* NY: Simon & Schuster.

Wellman, H., Hickling, A. K., & Schult, C. A. (2000). Young children's psychological, physical and biological explanations. In K. Lee (Ed.), *Childhood cognitive development: The essential readings* (pp. 267−288). Malden, MA: Blackwell.

Yokoyama, A. (2001). The trial of RAA (Robot Assisted Activity) with AIBO in the pediatrics ward at the general hospital. *Correspondences on Human Interface*, *3*, 1−4.

Yokoyama, A., Ribi, F.N., & Turner, D.C. (2004, October). *A comparison of Japanese and Swiss children's behavior toward a pet robot*. Paper presented to the International Conference on Human–Animal Interactions, Glasgow, Scotland.