SEARCHING FOR SIGNS OF INTELLIGENT LIFE: AN INVESTIGATION OF YOUNG CHILDREN'S BELIEFS ABOUT INTELLIGENCE AND ANIMACY

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The goal of this research project is to identify the source of children's ideas about the intelligence capabilities of robots. If children's beliefs are influenced by naïve biology theories, there is likely to be a strong relationship between animacy judgments (whether an entity is alive or not) and judgments of intelligence. However, if children's beliefs are influenced by prior experience with robots, there is no reason to assume intelligence and animacy would be related; rather, degree of prior exposure to robots would influence children's beliefs about robots' intelligence capabilities. Results suggest a relationship between animacy judgments and intelligence for children with little prior exposure to robots. For children with greater exposure, there is less of a relationship between intelligence and animacy judgments. Additionally, children with greater exposure attributed more intelligence to the robots than children with little exposure. It would seem that children with little robot experience are guided by their naïve theories of biology, while children with significant robot experience use ideas gathered from their prior experiences to make judgments about the intelligence capabilities of robots.

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PREFACE

I am grateful for the assistance provided by my advisor Kevin Crowley, and my masters committee members Christian Schunn and Michelene Chi. I would also like to thank Illah Nourbakhsh, Kristen Stubbs, and Emily Hamner from the Robotics Institute at Carnegie Mellon University; Sasha Palmquist, Catherine Eberbach, Jenna Brooks, Liza France, Anuja Parikh, Andrea Patterson, and Nora Webber at the University of Pittsburgh Center for Learning in Out-of-School Environments; and the staff and visitors at the Children's Museum of Pittsburgh. Thanks to my husband Lowell and the rest of my wonderful family for their support and encouragement. Finally, I would like to thank my nieces Alyssa and Emma for reminding me how smart and creative young children can be.

1.0 INTRODUCTION

“People who grew up in the world of the mechanical are more comfortable with a definition of what is alive that excludes all but the biological and resist shifting definitions of aliveness… Children who have grown up with computational objects don’t experience that dichotomy. They turn the dichotomy into a menu and cycle through its choices.” (Sherry Turkle, 1999)

Increasingly, our society is embracing technology in a variety of domains. So-called ‘smart’ technologies are now being employed for functions as diverse as house cleaning (e.g., the Roomba), inter-planetary exploration (e.g., the Mars Exploration Rovers), and children’s toys (e.g., Robosapien). Numerous authors and visionaries have suggested that this infusion of technology will result in significant, long-lasting changes to the way we think, perceive, and understand ourselves, as well as the technology around us (Papert, 1980; Pesce, 2000; Turkle, 1984, 1998, 1999).

As the quote from Turkle (1999) implies, there is already some evidence to suggest that exposure to intelligent technologies has changed the way children think about what it means to be alive (Kahn, Friedman, Perez-Granados, & Freier, 2004; Turkle, 1999). One way to think about this change is as a cohort effect – continuous exposure to intelligent technologies may be influencing an entire generation of children to think about the term “alive” in a different way. “Intelligence” is another concept that may be ripe for change in the world of smart technologies, especially as the technology available for home use becomes increasingly more sophisticated in its ability to engage in complex and autonomous behavior.

The motivating question behind the current research is this: are children's ideas about intelligence changing as a result of continuous exposure to intelligent technologies? One way to answer this question may be to simply ask children if they believe robots and other technologies are intelligent. Several researchers have done so, and found that young children are generally willing to attribute intelligence and other 'animistic' qualities to robots (see Kahn, Friedman, Perez-Granados & Freier, 2004; Okita, Schwartz, Shibata & Tokuda, 2005; Turkle, 1984; van Duuren & Scaife, 1996).

However, knowing that children attribute intelligence to robots does not necessarily tell us whether their fundamental ideas about intelligence have changed. In order to know that, we would have to understand where children's ideas about intelligence came from in the first place, and then show that exposure to intelligent technology has changed those ideas.

In answer to the first question, one potential origin for children's ideas about intelligence is naïve theories. Naïve theories are frameworks that organize children's knowledge and beliefs about the world in several fundamental domains, including biology, psychology, and physics. In particular, naïve biology theories are believed to organize children's knowledge about the characteristics of living things. These theories are causal, in that they allow children to make inferences about the animacy status and other characteristics of novel entities. The naïve biology literature suggests that children's beliefs about intelligence are tied into their naïve biology theories, meaning that children associate intelligence with living things.

But if it is the case that children's beliefs about intelligence are tied up in their naïve theories, is it possible for experience with technology to change those ideas? Research on the “cognitive ecology”, i.e., the collection of artifacts in a child’s world that facilitate thinking and interest on the part of the child, suggests that experiences with technology and other cultural phenomena can have a strong impact on children’s ideas.

The current research is designed to test the hypothesis that a cognitive ecology that includes intelligent technologies can change children’s ideas about intelligence. However, in order to prove that a change has occurred, we must provide evidence for two sub-hypotheses: (1) children with exposure to intelligent technologies make different assumptions about intelligence in non-living things than do children with little or no exposure; and (2) in the absence of this exposure, children’s ideas about intelligence are guided by their judgments of whether an entity is alive or not (i.e., are guided by their naïve biology). This pattern of findings would be consistent with the explanation that children move from believing intelligence is a characteristic of living things to understanding that there can be non-organic forms of intelligence.

For the purposes of this paper, intelligence is defined as the capability to acquire and manipulate or act upon information in an autonomous (independent) way. The term ‘animate’ is used to define a living entity; the term ‘animacy’ is used synonymously with ‘alive’.

1.1 THE LIVING/NON-LIVING DISTINCTION AND ITS IMPACT ON INTELLIGENCE JUDGMENTS

Developmental psychologists have long proposed that when children reason about the world, their reasoning is guided by, “…coherent bodies of knowledge that involve causal explanatory devices," or naïve theories (Inagaki & Hatano, 2002, p. 2). Naïve theories help to organize children's ideas, thus allowing them to make predictions, provide explanations, and integrate new information into their existing understanding (Inagaki & Hatano). These naïve theories are believed to be enduring, and to guide children's thinking in a number of realms, including biology, psychology and physics. For example, the development of a naïve theory of psychology is believed to guide children's understanding of the role of intentionality and mental states in cognition (Flavell, 1993; Wellman & Gelman, 1998).

The development of a naïve theory of biology is particularly relevant to the current work. At its broadest level, the naïve biology theory allows children to make inferences about the characteristics of entities, based upon their inclusion in (or exclusion from) the category of living things (Wellman & Gelman, 1998). Proponents of the naïve theory of biology suggest that children use their judgments of living/non-living status to guide decisions about the attribution of characteristics, and that the presence or absence of certain characteristics can be used to guide decisions about animacy (Gelman & Gottfried, 1996; Massey & Gelman, 1988; Richards & Siegler, 1986; Wellman & Gelman). For example, Richards and Siegler asked children between the ages of 4 and 11 to name the characteristics associated with living things (study 1), and determine whether an entity was alive based upon those characteristics (study 2). These researchers were able to identify developmental patterns in children's responses. Children aged 4 thru 7 were most likely to attribute features common only to animals, such as movement, to living things, whereas 8 to 11 year olds attributed features common to both plants and animals, such as eating and growth (as well as motion), to living things. These findings provide partial support for the naïve theory claim that children's beliefs about biology are consistent, causal (i.e., used to make predictions and generate explanations), and develop with age.

We know that children use their naïve biology knowledge to draw associations between the presence of certain characteristics (e.g., growth, movement) and judgments of animacy. Do children also approach decisions about a robot's characteristics by first deciding whether it is alive or not? If so, which of the robot's characteristics do they associate with animacy? And where does intelligence fit in? Is it the case that children think intelligence, like growth, can only exist in living things?

Unfortunately, this is not an easy question to answer. The majority of research has focused on intelligence as it is instantiated in living things (mostly people), making it difficult to parse out children's beliefs about intelligence and animacy. However, existing literature does suggest a relationship between intelligence and the presence or absence of a brain. Most children believe a brain is necessary for at least some intelligent acts. Johnson and Wellman's (1982) work in this area suggests that preschoolers believe the brain is involved in overtly mental acts (e.g., thinking). As children get older, they recognize that the brain is also necessary for sensory and motor activities, and for involuntary actions.

Scaife and van Duuren (1995) examined children's beliefs about whether a variety of artifacts had a brain. These researchers asked children aged 5 through adult whether a person, robot, computer, doll, and book had a brain, or "a sort of brain even though it is different from ours in some way" (p. 370). Approximately half of the 5 year olds believed that the robots had a brain, but only 20% believed the computer had a brain. As children got older, they were more likely to say that the robot and computer both had a brain. By 7 years old, children were attributing brains to the robot and computer nearly as often as adults were. Additionally, an analysis of response patterns indicated that children aged 7 and older were likely to attribute brains to the ‘cognitive set’ (person, robot, computer), indicating that, unlike the 5 year olds, they were basing their decisions on the cognitive features of the entities.

Following this work, Van Duuren and Scaife (1996) adapted the framework used in Johnson and Wellman (1982) to examine whether children believed robots and computers were capable of independently executing any of the actions children attributed to the brain. While the majority of 7 and 11 year olds believed that robots could perform motor tasks independently, fewer than half of the children in the study (aged 5, 7 and 11) believed robots or computers could perform any of the other tasks children typically attribute to the brain. Taken on the surface, these findings suggest that few children believe robots or computers are capable of intelligent behavior. However, it is worth noting that many of the actions Johnson and Wellman asked about, e.g., coughing, dreaming, feeling sad, are (currently) unique to biological entities. That children were unwilling to attribute those characteristics to robots and computers may say more about children’s unwillingness to extend these biological characteristics to non-living things than their beliefs about the intelligent capabilities of technology.

Davis (2004) also investigated the characteristics that children (ages 4-10) associated with having a mind and brain for a variety of non-human entities, including robots. Her research suggests that the presence of senses (e.g., seeing things), sensations (e.g., feeling hot/hurt), physical states (e.g., sleeping, getting sick), cognition (e.g., thinking/pretending) and intentional behavior all contribute significantly to children’s judgments of whether a given entity has a brain. It could be argued that some of these characteristics are only available to biological entities, leaving open the question of whether children’s perceptions of brain-related behavior differ for biological and non-biological entities. However, this research confirms that children see the brain as an important source of intelligence for biological and non-biological entities.

Taken together, this research suggests that children see a strong relationship between having a brain and being "intelligent" (i.e., being capable of acquiring and manipulating or acting upon information in autonomous way). Importantly, these findings reinforce the naïve theories approach of applying a set of fundamental beliefs to a particular situation – in this case, the beliefs specify what is required of an entity to be intelligent. In cases where these specifications apply, the entity will be granted intelligence.

However, there is some evidence that children do not always abide by the rules set out by naïve theories. A study by Opfer and Gelman (2001) asked preschoolers, 5^{th} graders and adults to predict whether a variety of entities (animals, plants, machines, simple artifacts) could engage in teleological (goal-seeking) behavior, a characteristic of living things. As predicted, the majority of preschoolers in the study stated that only animals were capable of goal-directed action, while adults knew that both animals and plants could act teleologically. Like the adults, the 5^{th} graders in the study knew that animals and plants could act teleologically. However, some 5^{th} graders also predicted that the machines (but not the simple artifacts) were capable of teleological action. Opfer and Gelman explained this finding by suggesting that children were responding to a "conflict of interest" between machines and designers, since "machines can embody the goals of their designers, and designers presumably design machines to act to benefit both the designers themselves and their creations" (p. 1380). Another interpretation of this finding might be that 5^{th} graders recognize some complex systems can monitor their own needs and take responsibility for filling those needs. However, this interpretation goes against the naïve theories view that children will only apply a characteristic of living things to entities they believe are alive.

Opfer and Gelman's (2001) findings raise the possibility that children may be willing to attribute certain behaviors to both living and non-living entities. In some ways, this finding is not surprising. A number of studies have suggested that children have alternative methods at their disposal for making decisions about the attribution of biological characteristics, such as reasoning by analogy from a familiar to an unfamiliar object (Inagaki & Hatano, 1987; Inagaki & Hatano, 2002). Additionally, a number of studies have found that children can distinguish between situations where it is appropriate to attribute behavior to biological or psychological causes and situations where it is inappropriate to do so, even if the situations seem superficially similar (Gelman & Gottfried, 1996; Massey & Gelman, 1988; Schult & Wellman, 1997).

In sum, it is unclear from the literature whether we can expect young children to extend their naïve biology beliefs to robots. Some research suggests that children will think about intelligence in robots the same way they think about intelligence in biological entities – as a fundamental state of being that is concordant with having a brain. However, other researchers have concluded that children's use of naïve theories is nuanced, making it difficult to predict how they will reason about novel entities. This uncertainty points to the possibility that there may be additional influences on children's beliefs.

1.2 THE ROLE OF PRIOR EXPERIENCE IN GUIDING CHILDREN'S BELIEFS

The expertise literature has made a strong argument for the influence of prior experience on children's knowledge representations and beliefs (Chi, Hutchinson, & Robin, 1989; Chi & Koeske, 1983; Means & Voss, 1985). Further investigations have shown a relationship between children’s knowledge and the presence of artifacts in the environment (Crowley & Jacobs, 2002; Leibham, Alexander, Johnson, Neitzel, & Reis-Henrie, 2005).

One way to understand the influence of environment on children is to think about their “cognitive ecology”, i.e., the collection of artifacts in a child’s world that facilitate thinking and interest on the part of the child (Palmquist & Crowley, in press). Crowley and Jacobs (2002) have argued that because these artifacts serve as a platform for exploration and discovery, the cognitive ecology can have a strong impact on children’s knowledge and beliefs.

Sherry Turkle’s sociological studies (1984, 1998, 1999) document more directly how the changing cognitive ecology of childhood has influenced the way children think about technology. For example, prior to the 1980’s the majority of children’s toys could be understood in terms of their physical mechanisms (e.g., a wind-up car can be understood in terms of its gears and springs). But as toys became digital and thus less physically transparent, children began to seek other explanations for why their toys behaved in certain ways. Turkle credits the digital revolution with pushing children towards a more “psychological” understanding of technology. In both her early and more recent work (1984, 1998), she cites numerous examples of children attributing consciousness to technology, such as the child who, when puzzled about why an electronic game kept beating him, accused the game of cheating. In this example, the child attributes intention and motivation to the game, in order to provide himself with an explanation of *why* the game kept winning.

It is these types of experiences that Turkle suggests can change children’s fundamental ideas about intelligent technologies. Imagine, for example, how repeated exposure to robots might change a child’s concept of what a robot is, and what a robot can do. I propose that these types of experiences may also help shape children's ideas about what it means to be intelligent, and allow them to include a non-organic form of intelligence within their concepts.

Recent research on children and robots has revealed that children already attribute a number of intelligence capabilities to robots. For example, Nigam and Klahr (2000) investigated children's attributions of cognition, volition and emotional states to a robot. These researchers found that children were willing to attribute these characteristics to a robot, and that certain characteristics, e.g., volition, were more likely to be attributed when children believed the robot was alive.

Okita, Schwartz, Shibata and Tokuda (2005) investigated the frequency with which children between the ages of 3 and 5 attributed animistic characteristics (i.e., characteristics that would be reasonable to attribute to living things), such as intentions, intelligence, and biological characteristics, to robotic pets. Results for studies 1 and 2 suggest that 3 year olds are more likely than 5 year olds to attribute biological functions and intentionality to robots. Older children's judgments were somewhat (but not always) more likely to be based upon the appearance and behavior of the robots. However, approximately 80% of children in study 1 attributed intelligence attributes to the robots (questions about intelligence were only asked in study 1). Age and the behavior of the robot did not influence children's judgments of whether the robots could perform the three tasks included in the 'intelligence' composite – making perceptual discriminations (e.g., telling the difference between a real and pretend bone), remembering, or making predictions. These authors do not specifically address whether animacy judgments influenced children's beliefs about the intelligence of the robots.

Both of these papers suggest that young children are willing to attribute mental states and other animistic characteristics to robots. But neither paper can tell us whether children have expanded their definitions of mental states to include actions by intelligent technologies, or whether children's attributions of mentalistic characteristics were driven by the fact that children believed the robots were alive. I suggest that this is a very important distinction. If children's judgments of intelligence capabilities to robots can be tied to their animacy judgments, then children have not created any new concepts for robots; rather, they are just expanding their biological theories to the robots. However, if children can be shown to attribute these characteristics to robots without believing they are alive, then perhaps children have formed new concepts of intelligence that include non-organic forms of intelligence.

2.0 METHOD

In this study, children were asked whether it is appropriate to attribute biological, intelligence and psychological characteristics to eight different entities. Children were also asked to justify their responses for certain key characteristics. Parents were asked to fill out a brief survey about their child's previous opportunities to learn about or interact with robots.

2.1 PARTICIPANTS

Sixty children participated in this study. There were thirty 4- and 5-year olds (15 girls and 15 boys; mean age = 62.6 months) and thirty 6- and 7-year olds (14 girls and 16 boys; mean age = 82.6 months). Participants were recruited from the population of weekend visitors at the Children's Museum of Pittsburgh.

The decision to conduct this study with children between the ages of 4 and 7 was guided by prior research, which suggests that early childhood is an important period for the development of naïve biology theories (Wellman & Gelman, 1998; Hatano, Siegler, Richards, Inagaki, Stavy & Wax, 1993). Children in this age range are beginning to understand that plants are alive, and that motion is a common, but not defining characteristic of life (Richards & Siegler, 1986). One of the goals of this study is to understand the challenge posed to naïve biology theories by potentially ambiguous (from an animacy perspective) entities, such as robots. Thus, young children seemed an appropriate target for this investigation.

2.2 MATERIALS

2.2.1 Forced-choice "bingo" task

The goal of the "bingo" task was to elicit children's beliefs about the characteristics of eight different entities: a person, cat, plant, doll, computer, calculator, humanoid robot (Sony QRIO), and rover (the Personal Exploration Rover). Children were given eight laminated 5" x 9" cards, each one containing a picture of a different entity. The name of the entity was printed on the bottom of the card. Both of the robots were simply labeled "robot".

While robots were the primary entities of interest in this study, children were also asked about three biological entities (person, cat, plant), two intelligent technologies (computer, calculator), and a control item (doll). The biological entities are included for comparison purposes. The calculator doubles as an electronic control item. If children attribute different characteristics to the calculator and the robots, I can assume that there is something special about the robots that is guiding their attributions, above and beyond electronic components (such as wires and batteries) which are also shared by the calculator. The doll serves both as a general control item, and as form-match control for the humanoid robot.

Throughout the course of the game, children were asked to judge whether each entity had the following characteristics: biological (alive, growth, metabolism, reproduction, self-generated movement), intelligence (think, remember, plan, calculate, learn, situational awareness), psychological (emotion and volition), and artifactual (made in a factory, put together). It was hoped that the inclusion of psychological questions would help distinguish between the presence of a mind and the presence of intelligence (Davis, 2004). One goal of the current research is to investigate the extent to which children have developed a theory of non-biological intelligence. Intelligence in the absence of psychological characteristics (i.e., intelligence *without* a mind) would be the truest instantiation of this theory. The artifactual questions were included in order to make sure that children recognized the robots as non-biological entities. See Appendix A for a list of complete questions.

The questions were printed on colored index cards. At the beginning of each turn, the child was asked to choose a question card. For each question card, children were asked to answer the question posed by placing a penny on the appropriate picture(s). For example, if asked, “Which things need food or water?” (metabolism question), the child might respond by placing a penny on the person, plant, and cat. The experimenter would ask the child if there were any other things that needed food or water. After the child decided that he/she had indicated all the entities that needed food or water, the experimenter invited the child to pick up all the pennies. The child then chose another card, and game play continued. Children continued to choose cards until there were none left.

The question on ‘situational awareness’ was asked of all participants, but excluded from analysis. This question was intended to ascertain if children believed the entity was aware of its surroundings; however, the question was often misinterpreted to mean the ability of the entity to be moved to different locations.

2.2.2 Parent survey

The parent survey consisted of 11 questions. The first five questions asked about the availability of robotic toys and/or educational materials about robots in the home. A series of Likert scale questions asked parents to rate (on a scale of 1-7) their child's interest in and knowledge about robots, as well as their own robot interest and knowledge. Parents were also asked to rate their children's interest in computers, and to estimate the amount of time the child spends per week using the computer. See Appendix B for a copy of the parent survey.

2.3 DESIGN AND PROCEDURE

All data was collected in the UPCLOSE lab space at the Children's Museum of Pittsburgh. Families were recruited during their visit to the museum. Average participation time in this study was 19 minutes, 52 seconds. All aspects of data collection were videotaped.

All children participated in the forced-choice task first. Children were first asked to label each of the eight entities on the cards. If a child was unable to label any items, the experimenter would provide the name of the item, and then ask the child to repeat it back. In order to make sure children understood the task, each child was asked two practice questions: "Which cards have things on them that can make noise?" and "Which cards have things on them that you have in your house?" Children were instructed to place a penny on each picture that answered the question. The majority of children understood this procedure after the first practice question. Following the practice questions, children began picking questions from the pile of colored index cards. While the order of the practice questions was fixed, the order of experimental questions was always randomized, as each child picked the cards in a different order. Parents were asked to complete the survey while their children participated in the forced-choice task.

After completing the forced-choice task, children were asked three additional questions: *How did you know that ____ were alive and the other things weren't? How did you know that ____ could think and the other things couldn't? How did you know that ___ could feel happy or sad and the other things couldn't?* For each question, the experimenter reiterated children's responses to the alive, think and emotion questions. If children were unable to answer the question as posed, the experimenter followed up by probing individual items, i.e., "how did you know that robot could think?" These additional questions were designed to elicit justifications for children's forced-choice responses.

3.0 RESULTS

The analysis begins with a summary of the types of characteristics children attributed to the eight entities (person, cat, plant, humanoid robot, rover, computer, calculator, doll). Following this summary, I present two sets of analyses conducted on the forced-choice data. The first set of analyses examines the relationship between children's judgments of 'alive', and their attributions of intelligence (and other characteristics) to the entities, with a particular focus on children's treatment of the robots. The second set of analyses examines the relationship between a child's opportunity score, a measure of prior exposure to robots, and their attributions of intelligence to the robots. I then present a summary of children's responses to the justification questions.

3.1 FORCED-CHOICE TASK

3.1.1 Summary of forced-choice data

3.1.1.1 Biological and intelligence characteristics. Figure 1 summarizes the mean number of biological and intelligence characteristics (out of 5) attributed to each of the eight entities in the forced-choice task. On average, children attributed nearly all of the biological characteristics to the person (*M*=4.97, *SD*=0.18) and cat (*M*=4.85, *SD*=0.48), but fewer to the plant (*M*=2.8, *SD*=1.0). Children also attributed nearly all of the intelligence characteristics to the person (*M*=4.88, *SD*=0.32), but fewer to the cat (*M*=3.27, *SD*=1.05). Very few children attributed any intelligence characteristics to the plant (*M*=0.08, *SD*=0.33). See Table 1 for a breakdown of the specific characteristics attributed to each of the eight entities. See Appendix C for correlation matrices that show relationships between the different characteristics.

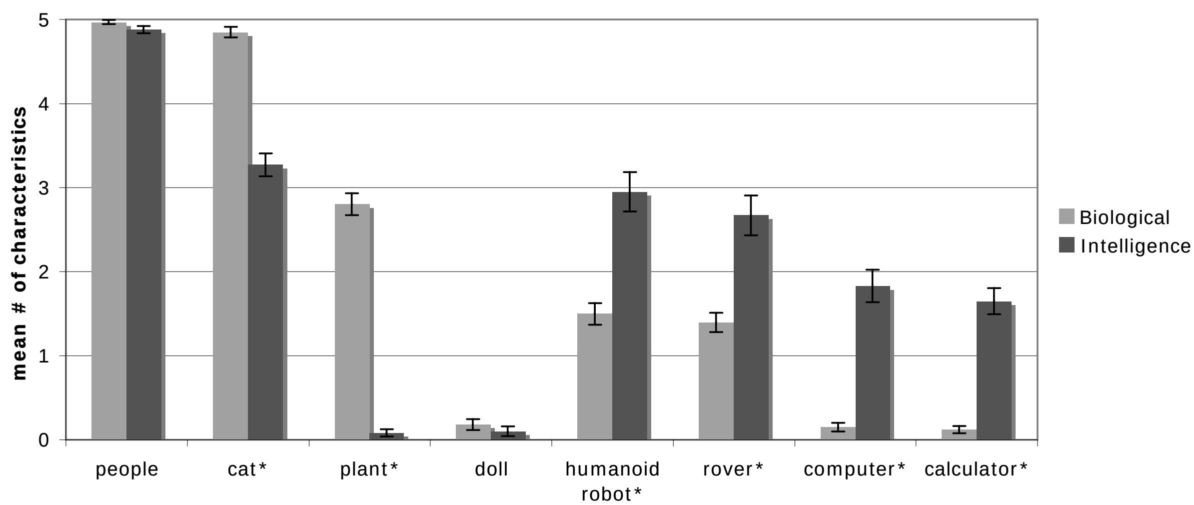

Figure 1: Mean number of biological and intelligence characteristics (out of 5) attributed to each entity.
* significant difference between total # of biological and intelligence characteristics, p < .006

Table 1. Percentage of children attributing characteristics to each of the 8 entities.

	Person	Cat	Plant	Computer	Humanoid Robot	Rover	Calculator	Doll
Biological Characteristics								
Alive	100	100	63	13	42	37	12	5
Grow	100	92	93	2	5	5	0	2
Reproduce	97	95	23	0	13	10	0	5
Eat	100	98	95	0	7	5	0	2
Move	100	100	5	0	83	83	0	5
Intelligence Characteristics								
Calculate	90	10	0	77	53	47	93	2
Learn	100	87	4	18	55	50	13	2
Remember	100	67	2	28	53	45	15	0
Plan	98	73	3	33	73	67	23	3
Situational Awareness	100	93	13	10	63	55	7	15
Think	100	90	0	27	60	58	20	3
Psychological Characteristics								
Emotion	100	93	10	3	37	30	2	12
Volition	100	67	5	20	50	52	13	3
Artifactual Attributes								
Put Together	17	12	8	90	97	97	83	78
Made in a Factory	2	2	12	85	93	92	85	82

While children attributed more biological than intelligence characteristics to the biological entities (i.e., person, cat and plant), the opposite was true for the intelligent artifacts. On average, children attributed more than half of the intelligence characteristics to the humanoid robot (M=2.95, SD=1.82), but fewer biological characteristics (M=1.5, SD=1.0). The same pattern held true for the rover (intelligence, M=2.67, SD=1.82; biological, M=1.4, SD=0.89). The attribution of self-generated movement accounted for the majority of the biological score associated with each robot. Children also attributed more intelligence than biological characteristics to the computer (intelligence, M=1.83, SD=1.49; biological, M=0.15, SD=0.4) and calculator (intelligence, M=1.65, SD=1.42; biological, M=0.12, SD=0.32). The ability to calculate accounted for the majority of the intelligence scores associated with the computer and calculator.

A series of paired t-tests (with Bonferroni correction) were conducted in order to determine if there was any relationship between the number of intelligence and biological characteristics assigned to each entity. This analysis revealed significant differences for six of the entities: cat, $t(59) = 12.99$; plant, $t(59) = 21.19$; humanoid robot, $t(59) = -6.98$; rover, $t(59) = -6.24$; computer, $t(59) = -8.82$; calculator, $t(59) = -9.9$; $p < .00625$ for all comparisons[1]. No significant differences were found for the person or the doll, which were at ceiling and floor (respectively) for all characteristics (see Figure 1). This result indicates that there is not a global relationship between the number of biological and intelligence characteristics possessed by an entity.

Few children attributed any biological or intelligence characteristics to the doll (biological, *M*=0.18, *SD*=0.5; intelligence, *M*=0.1, *SD*=0.44). This finding indicates that the doll was a successful control artifact. If children had assigned biological and intelligence characteristics to the doll, as well as the other artifacts, I might have speculated that participants were simply overattributing to all the artifacts. However, the fact that so few children attributed any characteristics to the doll indicates that this was not the case.

Figure 2 displays children's attributions of biological and intelligence characteristics to all eight entities. From this figure, we can see three distinct grouping of entities: intelligent and biological entities (the person and cat); intelligent and mobile technologies (the humanoid robot and rover); and somewhat intelligent but non-mobile technologies (the computer and calculator). The plant is treated separately from the other biological entities. The doll is treated separately from the intelligent artifacts.

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[1] All analyses presented in this paper are two-tailed.

It is interesting to notice that children grouped both the humanoid robot and rover together, as these robots have quite different forms. This finding confirms that children did not attribute characteristics to the humanoid robot based solely upon its anthropomorphic appearance, but focused on its classification as an intelligent technology when making decisions about its characteristics.

The grouping of the computer and calculator may be surprising to adults, as the computer is more similar to a robot than a calculator in terms of its computational ability. However, figure 2 seems to indicate a relationship between intelligence and motion – the four entities judged to move independently were also judged to be the most intelligent. The lack of motion in the computer and calculator may have led children to group these entities together, just as the perceived lack of motion in the plant may have led children to treat it separately from the other biological entities.

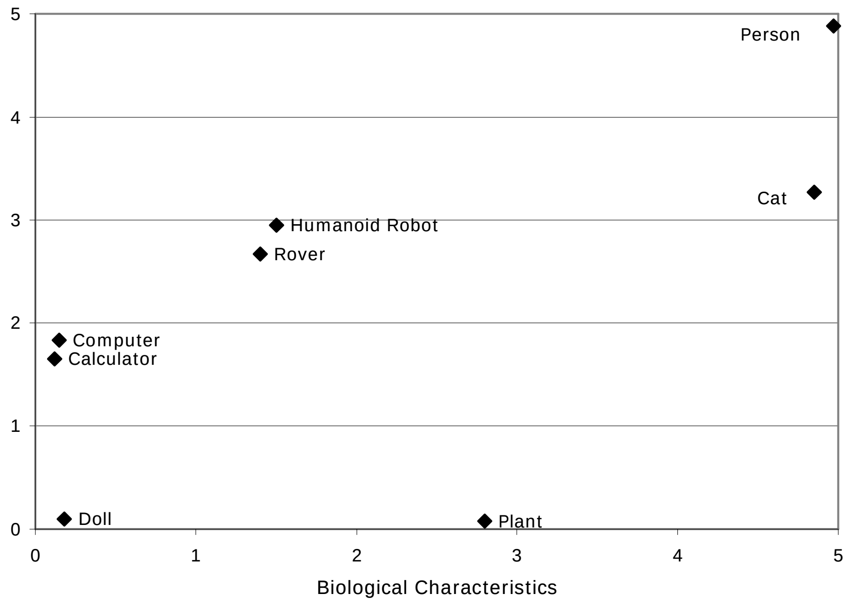

Figure 2. Distribution of intelligence and biological characteristics for all 8 entities.

3.1.1.2. Psychological characteristics. Figure 3 summarizes the mean number of psychological characteristics children attributed to the eight entities. All children attributed both psychological characteristics (emotion and volition) to the person. On average, children attributed almost as many psychological characteristics to the cat (*M*=1.6, *SD*=0.58), but fewer to the humanoid robot (*M*=0.87, *SD*=0.83) and the rover (*M*=0.82, *SD*=0.81). Children attributed very few psychological characteristics to the plant (*M*=0.15, *SD*=0.4), doll (*M*=0.15, *SD*=0.4), computer (*M*=0.23, *SD*=0.5), and calculator (*M*=0.15, *SD*=0.4).

Correlations were run to determine the relationship between children's attributions of psychological and intelligence characteristics. The absence of such a relationship would indicate the belief that an entity could be intelligent without having a mind. However, analyses revealed significant correlations between the number of intelligence and psychological characteristics attributed to the humanoid robot ($r = .62, p < .001$), rover ($r = .67, p < .001$), computer ($r = .42, p < .01$), and cat ($r = .48, p < .001$). One interpretation of this result is that children do not think entities can be intelligent without having psychological characteristics. An alternative interpretation, supported by Davis' (2004) work, is that young children often group psychological and intelligence characteristics together because they do not make the same types of distinctions between the mind and brain as adults do.

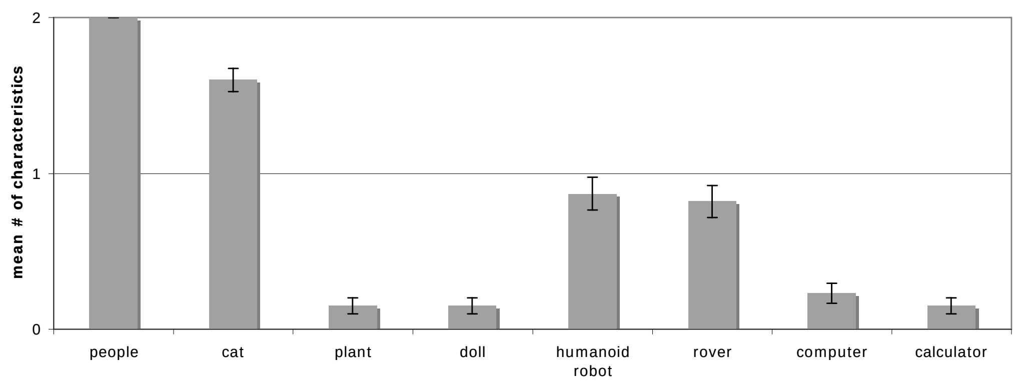

Figure 3: Mean number of psychological characteristics (out of 2) attributed to each entity.

3.1.2 The relationship between 'alive' and intelligence.

One way to determine whether children use their naïve theories to guide decisions about the capabilities of intelligent technologies is to ask whether children are more likely to attribute intelligence and biological characteristics to entities they believe are alive. This section presents an analysis of the relationship between animacy judgments (whether the entity is alive or not) and the attribution of biological and intelligence characteristics.

All 60 children in this study responded that both the person and cat were alive. Only three children said the doll was alive. Thirty-eight children (15 younger, 23 older) said that the plant was alive. Consistent with prior literature (e.g., Hatano, Siegler, Richards, Inagaki, Stavy & Wax, 1993), there was a significant relationship between age and the attribution of animacy to the plant, χ^2 (1, *N*=60) = 4.59, p < .04. While there were no differences in children's intelligence attributions to the plant based upon animacy judgments, children who judged the plant to be alive attributed significantly more biological characteristics to the plant than children who did not say it was alive[2], *M* (alive) = 2.4, *M* (not alive) = 1.8, t(58) = -3.06, p < .005.

Twenty-five children (42%) judged the humanoid robot to be alive, and twenty-two (37%) judged the rover to be alive. Age was not a factor in making animacy decisions about either robot – younger children were no more likely than older children to say the robots were alive. It should be noted that when asked about the artifactual properties of the robots, 56 out of 60 children responded that the humanoid robot was made in a factory, and 55 out of 60 children responded that the rover was made in a factory. Of the children who said the robots were alive, over 95% also said the robots were made in a factory. Children's willingness to attribute both artifactual and animate properties to the robots has led some researchers to speculate that the term 'alive' may mean something different when applied to biological entities and intelligent technologies (Kahn, Friedman, Perez-Granados & Freier, 2004).

Yet despite children's recognition of the artifactual attributes of the robots, there was a significant relationship between children's judgments of animacy and the attribution of

[2] Whenever comparisons are being made based upon animacy judgments, the composite score "biological characteristics" only includes children's judgments of growth, metabolism, self-generated movement and reproduction. Means are out of 4.

biological characteristics to each robot. Children who said the humanoid robot was alive attributed significantly more biological characteristics to it than those who did not say it was alive, *M* (alive) = 1.4, *M* (not alive) = .86, t(36.4) = -2.96, p < .006. This finding is largely mediated by the significant relationship between judgments of animacy and self-generated movement, χ^2 (1, *N*=60) = 4.95, p < .03[3]. Children who said the rover was alive also attributed significantly more biological characteristics to it than those who did not say it was alive, *M* (alive) = 1.3, *M* (not alive) = 0.9, t(58) = -2.41, p < .02.

There is also a significant relationship between animacy and the attribution of intelligence characteristics to each robot. A two-way ANOVA with age (older/younger) and animacy judgment for the humanoid robot (alive/not alive) as the independent variables and number of intelligence characteristics to the humanoid robot as the dependent variable yielded a significant main effect for animacy, *F*(1,56) = 11.05, p < .003, no main effect for age, and no interaction. Mean number of intelligence characteristics attributed to the humanoid robot were as follows: *M* (alive) = 3.8, *M* (not alive) = 2.3. A similar ANOVA was run for the rover, and yielded a significant main effect for animacy, *F*(1,56) = 11.99, p < .002, no main effect for age, and no interaction. Mean number of intelligence characteristics attributed to the rover were as follows: *M* (alive) = 3.6, *M* (not alive) = 2.1.

Eight children (6 younger, 2 older) judged the computer to be alive, although there was no significant relationship between age and animacy judgments for the computer. There were no significant relationships between children's judgments of animacy and the number of intelligence or biological characteristics attributed to the computer. Seven children (6 younger, 1 older) judged the calculator to be alive. There was a significant relationship between age and

[3] If movement were removed from the composite of biological characteristics, the relationship between animacy judgments and the number of biological characteristics attributed to each robot would be non-significant.

animacy judgments for the calculator, χ^2 (1, N=60) = 4.04, $p < .05$, such that younger children were more likely to say the calculator was alive. As with the computer, there were no significant relationships between children's judgments of animacy and the number of intelligence characteristics attributed to the calculator (other than saying it was alive, no children attributed biological characteristics to the calculator).

These results suggest that the relationship between animacy and intelligence characteristics differs for the biological entities and the intelligent technologies. While animacy judgments were unrelated to intelligence for the plant, children judging the robots to be alive attributed significantly more intelligence to them than children who said the robots were not alive. On the surface, these findings suggest a relationship between animacy judgments and decisions about intelligence – perhaps children are using animacy judgments to guide decisions about intelligence for the artifacts (or vice versa). However, in the next section we will see that this relationship is mediated by children's prior experience with robots.

3.1.3. The impact of prior experience with robots.

In order to determine if children's prior experience with robots impacted their beliefs about the robot's capabilities, I conducted a series of analyses to examine differences in attribution patterns based upon experience.

Children's prior experience with robots was quantified using information gathered in the parent surveys. Children received one point for each of the robot-related activities they participated in, such as visiting a museum exhibit about robots, building a robot, or visiting a website about robots. Children also received one point for each of the robot-themed items present in their home environment, e.g., robot books, robot videos, or robot toys such as Lego Mindstorms or Bionicles. These points were summed into an opportunity score. A higher score indicated a greater opportunity for the child to learn about robots in his/her home environment. Opportunity scores ranged from 0 to 7, with a mean score of 2.46 (*SD* = 1.74). See figure 4 for the distribution of Opportunity Scores.

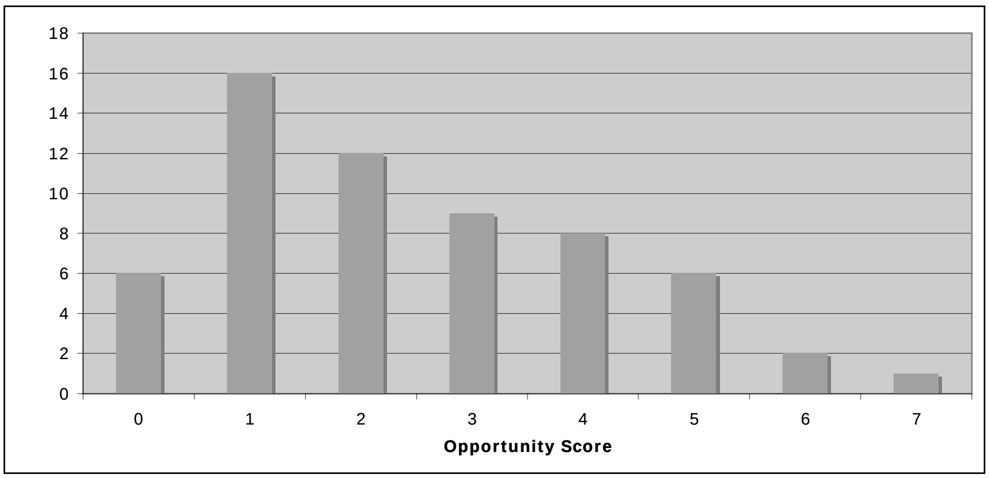

Figure 4: Distribution of children's Opportunity Scores

Based upon their opportunity scores, children were designated as having low opportunity (scores of 0, 1, 2, n = 34) or high opportunity (scores of 3 or higher, n = 26) to learn about robots in the home environment. The mean age of the low opportunity group was 70.6 months. This group contained 10 boys and 24 girls. The mean age of the high opportunity group was 75.2 months. This group contained 21 boys and 5 girls. The age difference between the low and high opportunity groups was not significant. However, a chi-squared analysis revealed a significant relationship between gender and opportunity group, χ^2 (1, N=60) = 15.56, p < .001, indicating that girls are significantly more likely than boys to be in the low opportunity group.

In order to determine the impact of prior experience on children's ideas about robot intelligence, a 2-way ANOVA was conducted with age (younger/older) and opportunity score (low/high) as independent variables, and the number of intelligence characteristics attributed to the humanoid robot as a dependent variable. This analysis yielded a main effect for opportunity score, $F(1,56) = 5.41$, $p < .03$, no main effect for age, and no interaction. On average, children with low and high opportunity scores attributed 2.49 and 3.54 (out of 5) intelligence characteristics to the humanoid robot, respectively. A similar analysis conducted for the rover yielded a main effect for opportunity score, $F(1,56) = 4.96$, $p < .04$, no main effect for age, and no interaction. On average, children with low and high opportunity scores attributed 2.24 and 3.25 (out of 5) intelligence characteristics to the rover, respectively. These analyses indicate that opportunity score had a larger impact than age on children's beliefs.

In order to make sure that children with high opportunity scores were not globally attributing more characteristics to the robots, a 2-way ANOVA was conducted with age and opportunity score as the independent variables, and the number of biological characteristics attributed to the humanoid robot as a dependent variable. This analysis revealed no main effect for opportunity score, no main effect for age, and no interaction. The same analysis for the rover also revealed no main effects and no interaction. Thus, we can conclude that children with high opportunity scores attributed more intelligence characteristics to the robots, but not more biological characteristics.

The next set of analyses examined the relationship between animacy and intelligence attributions for children in the low and high opportunity groups. A 2-way ANOVA was conducted with opportunity score (low/high) and animacy judgment (alive/not alive) as the independent variables, and the number of intelligence characteristics attributed to the humanoid robot as the dependent variable. This analysis revealed a main effect for animacy judgment, $F(1,56) = 9.95$, $p < .004$, a marginal main effect for opportunity score, $F(1,56) = 3.92$, $p = .053$, and no interaction. On average, children who judged the humanoid robot to be alive attributed 3.83 (out of 5) intelligence characteristics, while children judging the humanoid robot not alive attributed 2.47 intelligence characteristics. A similar analysis for the rover revealed a main effect for animacy judgment, $F(1,56) = 10.04$, $p < .003$, a non-significant main effect for opportunity score, $F(1,56) = 3.37$, $p = .072$, and no interaction. On average, children who judged the rover to be alive attributed 3.63 (out of 5) intelligence characteristics, while children judging the rover not alive attributed 2.23 intelligence characteristics.

Analyses laid out in the table below (Table 2) further explore the different relationship between animacy and intelligence for children with low and high opportunity scores. For children with low opportunity scores, animacy was a significant factor in the attribution of intelligence characteristics to the humanoid robot. Low opportunity children attributed learning, remembering, and planning significantly more often to the humanoid robot when they believed it was alive. For high opportunity children, animacy was only a factor in the attribution of learning (and marginally in the attribution of planning). It would seem that for children in the low opportunity group, the attribution of intelligence characteristics was closely linked to animacy judgments. This was not the case to as great an extent for children in the high opportunity group.

Table 2. Analyses of children's attributions of intelligence to the humanoid robot, broken down by opportunity score and animacy judgments. Values indicate proportion of children in each category who said the robot had each characteristic.

	Low Opportunity scores			**High Opportunity Scores**		
	Not Alive (n=22)	Alive (n=12)	**Significant Differences? (p values)**	Not Alive (n=13)	Alive (n=13)	**Significant Differences? (p values)**
Learn	.27	.67	.026	.46	1.0	.003
Remember	.23	.75	.002	.62	.77	NS
Plan	.59	.92	.023	.62	.92	NS (p = .07)
Calculate	.36	.58	NS	.69	.62	NS
Think	.41	.67	NS	.69	.77	NS
Total Intelligence Characteristics	1.86	3.58	.006	3.08	4.08	NS

Data were also classified by animacy judgment to determine if this was a more effective analysis strategy. T-tests revealed no significant differences between intelligence attributions for low and high opportunity children who said the robot was not alive (*M* low opportunity = 1.86; *M* high opportunity = 3.08; $t(33) = -1.92$, $p = .063$). Similarly, no significant differences in intelligence attributions were found among children who said the robot was alive (*M* low opportunity = 3.58; *M* high opportunity = 2.08; $t(23) = -.94$, $p > .05$).

The final set of analyses examined whether the relationships between entities differed as a function of prior experience with robots, i.e., did children with different levels of prior experience group the intelligent technologies differently? A repeated-measures ANOVA was conducted with the number of intelligence characteristics attributed to the 4 artificially intelligent entities (humanoid robot, rover, computer, calculator) as a within-subjects factor and opportunity score (low/hi) as a between-subjects factor[4]. This analysis revealed a significant effect for entity, $F(1.74, 100.68) = 18.12$, $p < .001$, a significant effect for opportunity score, $F(1,58) = 9.83$, p <

[4] Mauchly's test of sphericity was significant (Mauchly's $W = 0.304$, $df = 5$, $p = .00$), so the Huynh-Feldt correction was applied.

.004, and no significant interaction. Table 3 shows the mean number of intelligence characteristics attributed to each entity.

Table 3. Mean number of intelligence characteristics attributed to intelligent technologies, broken down by opportunity score. Standard deviations are in parenthesis.

	Low Opportunity Score	**High Opportunity Score**
Humanoid robot	2.47 (1.81)	3.58 (1.65)
Rover	2.21 (1.81)	3.27 (1.71)
Computer	1.38 (1.18)	2.42 (1.65)
Calculator	1.38 (0.85)	2.0 (1.5)

On the whole, high opportunity children attributed more intelligence to the intelligent technologies than did low opportunity children. Pairwise comparisons indicate that children attributed significantly more intelligence characteristics to the robots than to the computer or calculator, but there were no significant differences between the number of intelligence characteristics attributed to the humanoid robot and rover, or to the computer and calculator. The general pattern of treating the robots similarly, and treating the computer and calculator similarly, held for children with low and high opportunity scores.

An additional analysis was conducted to determine if opportunity impacted the way children thought about intelligence in technological vs. biological entities. Using the cat as a biological comparison point, a repeated-measures ANOVA was conducted with the number of intelligence characteristics attributed to the cat and humanoid robot as a within-subjects factor, and opportunity score (low/hi) as a between-subjects factor. This analysis revealed a significant interaction between entity (cat/humanoid robot) and opportunity score, $F(1,58) = 4.88$, $p < .04$, and a marginal main effect for opportunity, $F(1,58) = 3.99$, $p = .051$. Both groups of children attributed a similar amount of intelligence to the cat, but low opportunity children rated the cat as more intelligent than the robot (*M* = 3.24 for the cat, *M* = 2.47 for the humanoid robot), while high opportunity children rated the robot as slightly more intelligent than the cat (*M* = 3.3 for the cat, *M* = 3.58 for the humanoid robot). Paired t-tests reveal the specific intelligence characteristics contributing to this finding. Low opportunity children were significantly more likely to attribute learning, $t(33) = 5.17$, $p < .001$, remembering, $t(33) = 2.26$, $p < .04$, and thinking, $t(33) = 4.04$, $p < .001$, to the cat than to the humanoid robot. High opportunity children attributed these characteristics to the cat and the humanoid robot equally often. In both groups, children were significantly more likely to say the humanoid robot could add numbers together than the cat, low opportunity group $t(33) = -4.24$, $p < .001$, high opportunity group $t(25) = -4.72$, $p < .001$.

In sum, comparisons between low and high opportunity groups suggest that children who have had prior experience with robots view them as more intelligent (but no more biological) than those without prior experience. Additional analyses suggest that the relationship between animacy and intelligence may depend upon the child's prior experience with robots. This relationship seems to be stronger for children with little prior robot experience. Finally, children with prior robot experience position robots in a different place on the intelligence continuum than their inexperienced peers. Experienced children view robots as possessing intelligence capabilities similar to those of a cat, whereas inexperienced children view robots as less intelligent than animals.

3.2 JUSTIFICATION QUESTIONS

In addition to examining children's patterns of characteristic attributions to different entities, it is also important to determine the reasoning behind those decisions. Knowing why children made the choices they did may help us understand whether children were extending their biological ideas to the intelligent technologies, or whether they were thinking about the intelligent technologies in a different way. This section will describe children's justifications for their responses to the 'alive' and 'think' questions.

3.2.1 Coding.

Upon completion of the bingo task, children were asked to justify their answers to the forced-choice questions about animacy, thinking, and emotion. A coding scheme was developed in order to categorize children's justification responses. This coding scheme originally contained 23 independent codes, with an additional layer of coding available for negations (e.g., the response "because it can move" was coded as *movement*, whereas the response "because it can't move" was coded as *lacks movement*). For the purposes of analysis, the 23 codes have been collapsed into 13 higher-level categories (see Table 4). The development of this coding scheme was partially influenced by the work of Kahn, Friedman, Freier and Severson (2003), whose coding manual for children's responses to questions about AIBO (a robotic dog) includes the categories of biological features, biological processes, artifactual features, artifactual processes, reality status, and a separate set of codes for negations.

Inter-rater reliability was calculated for the initial set of 23 codes. Two independent raters coded 20% of the sample, and inter-rater reliability was calculated at 88%. A single rater coded the remainder of the data.

Asking children to justify their responses to three questions for eight different entities yields a total of 24 potential justifications from each child. Given the age of participants and the length of the study, it was decided that when justification probes were required (i.e., when children did not respond to the initial question of “how do you know ___ were alive and the other things weren’t?”), these follow-ups would be prioritized in order to maximize the number of justification responses provided for the robots. For this reason, almost all children were asked to justify their responses about the robots. However, the number of justifications requested for the other entities varied (see tables 5 and 6 for details). Due to experimenter error, five children were not asked the justification questions.

Table 4. Coding for the justification questions.

Higher-Order Categories	**Original List of Codes**
Source of knowledge	Innate knowledge (e.g., I just know…)
	Indirect experience (e.g., my teacher told me…)
	Direct experience (e.g., I have a computer so I know it can think)
	Analogy
	Categorization (e.g., because animal's can't do that…)
Brain	Artificial brain/made brain
	Brain
Artifactual actions/features	Artifactual actions (e.g., beeps, rolls, turn on/off)
	Artifactual feature (e.g., stuffing, wires, motor, batteries)
Biological action/features	Biological actions (e.g., sleep, talk, eat/drink, grow, get hurt)
	Biological feature (e.g., blood, mouth, body parts)
Movement	Movement
Autonomy	Autonomous action, not otherwise specified (e.g., because it does things on its own)
Person in control	Reference to control – person controls artifact (e.g., I play on it, I give it directions)
	Reference to control – artifact responds to user (e.g., follows directions)
Artifact construction	Reference to programming/building for a specific purpose (e.g., it's programmed/built to do that)
	Reference to building process in general (e.g., it was made in a factory)
Animacy status	Animacy status (e.g., it's alive)
Reality Status	Reality status (e.g., because it's real)
Cognitive processes	Cognitive processes (e.g., remembers, knows things)
Experience/display emotion	Experiences/displays emotion
Other	Don't know
	Inaudible

3.2.2 Analysis

The goal of the justification question analysis was to determine whether children used different criteria for assigning animacy and intelligence to biological and technological entities. Table 5 provides a summary of the most frequently provided justifications to the 'alive' question, broken down by entity and animacy judgment. Table 6 provides a summary of the most frequently provided justifications to the 'think' question.

3.2.2.1 Alive. When children were asked how they knew the biological entities were alive, the most common response categories were *movement* (i.e., because they can move; 23% of children gave this response for the person, 22% for the cat, 17% for the plant)[5], *biological action/features* (i.e., because they grow, eat, talk, have a face, etc.; 21% for the person, 22% for the cat, 43% for the plant), and a citation of the *knowledge source* (e.g., because the child has had experience with the entity, 33% for the person, 19% for the cat, and 17% for the plant). When children were asked why they believed the robots were alive, the majority of children cited *movement* as the reason for their decision (55% for the humanoid robot, 53% for the rover). The most common justifications for why the robots were not alive included *artifact construction* (i.e., because they were made; 28% for the humanoid robot, 26% for the rover), and the *lack of biological actions or features* (16% for the humanoid robot, 15% for the rover). The lack of biological actions or features was also a common justification for why the computer and calculator were not alive.

[5] Percentages are out of the number of children who responded to each question. For example 39 children responded to the question of how they knew the person was alive. Of those 39, nine answered 'movement', yielding 23%.

3.2.2.2 Think. When children were asked how they knew the cat and person could think, the most common response was because they had a *brain* (39% of children gave this response for the person, 44% for the cat). When asked how they knew the robots could think, 18% of children said the humanoid robot had a brain, and 19% said the rover had a *brain*. Other common response categories for the robots were *cognitive processes* (i.e., because they can remember, add, etc.; 12% for the humanoid robot, 13% for the rover), *artifact construction* (i.e., because they were built that way; 12% for the humanoid robot, 13% for the rover), and *person in control* (12% for the humanoid robot, 13% for the rover). Children who said the robots could not think often justified their responses by saying the robots did not have a *brain* (36% gave this response for the humanoid robot, 33% gave this response for the rover).

3.2.2.3. Summary. When questioned about animacy judgments, children used some of the same categories of responses to justify their decisions for biological and technological entities. Specifically, children seem to associate motion with animacy for both biological entities and robots. Children also associate biological processes and features with life, and use the lack of these features as a justification for withholding animacy status from technological entities. When questioned about thinking, children often used the presence or absence of a brain to justify their responses for both biological and technological entities.

Table 5. Most common justifications given for animacy judgments. The numbers in italics at the top of each box are the number of children who responded that a given entity was alive or not alive, and in parenthesis the number of children who were asked to justify this response. Some children provided more than one response.

Entity	**Animacy Judgment: Not Alive**	**Animacy Judgment: Alive**
Person	*n/a*	*n=60 (39 asked to justify)* Source of knowledge (13) Movement (9) Biological actions/features (8) Don't know/inaudible (12)
Cat	*n/a*	*n=60 (36)* Source of knowledge (7) Biological actions/features (8) Movement (8) Don't know/inaudible (13)
Plant	*n=22 (6 asked to justify)* Don't know/inaudible (2)	*n=38 (23)* Biological actions/features (10) Movement (4) Source of knowledge (4) Don't know/inaudible (5)
Humanoid robot	*n=35 (32)* Artifact construction (9) No biological actions/features (5) Source of knowledge (5) Don't know/inaudible (8)	*n=25 (22)* Movement (12) Source of knowledge (4) Don't know/inaudible (4)
Rover	*n=38 (34)* Artifact construction (9) No biological actions/features (5) Don't know/inaudible (8)	*n=22 (19)* Movement (10) Source of knowledge (4) Don't know/inaudible (4)
Computer	*n=52 (27)* No biological actions/features (7) No movement (5) Don't know/inaudible (5)	*n=8 (3)* Artifactual actions/features (1) Person in control (1) Don't know/inaudible (1)
Calculator	*n=53 (14)* Artifact construction (4) No biological actions/features (4) No movement (3)	*N=7 (3)* Artifactual actions/features (1) Autonomy (1) Don't know/inaudible (1)
Doll	*n=57 (17)* No movement (4) Artifact construction (3) Source of knowledge (3) Don't know/inaudible (2)	*n=3 (1)* Don't know/inaudible (1)

Table 6. Most common justifications given for ‘think’ judgments. The numbers in italics at the top of each box are the number of children who responded that a given entity could think or not, and in parenthesis the number of children who were asked to justify this response. Some children provided more than one response.

Entity	**Think Judgment: Cannot Think**	**Think Judgment: Can Think**
Person	*n/a*	*n=60 (33 asked to justify)* Brain (13) Source of knowledge (5) Don’t know/inaudible (11)
Cat	*n=6 (2)* No Brain (1) Don’t know/inaudible (1)	*n=54 (27)* Brain (12) Don’t know/inaudible (9)
Plant	*n=60 (3)* No brain (2) Biological actions/features (1)	*n/a*
Humanoid robot	*n=24 (14)* No brain (5) Source of knowledge (3) Don’t know/inaudible (1)	*n=36 (33)* Brain (6) Person in control (4) Artifact construction (4) Cognitive processes (4) Don’t know/inaudible (12)
Rover	*n=25 (15)* No brain (5) No biological actions/features (2) Source of knowledge (2) Don’t know/inaudible (2)	*n=35 (32)* Brain (6) Cognitive processes (4) Artifact Construction (4) Person in Control (4) Don’t know/inaudible (10)
Computer	*n=44 (20)* No brain (5) No animacy /not alive (4) Don’t know/inaudible (6)	*n=16 (13)* Brain (4) Artifact actions/features (4) Source of knowledge (3) Don’t know/inaudible (0)
Calculator	*n=48 (8)* No brain (2) No animacy/not alive (2) Don’t know/inaudible (1)	*n=12 (9)* Person in control (4) Cognitive processes (2) Don’t know/inaudible (2)
Doll	*n=58 (10)* Source of knowledge (4) No brain (2) Don’t know/inaudible (1)	*n=2 (1)* Cognitive processes (1) Brain (1)

4.0 DISCUSSION

The goal of this study was to determine whether children's beliefs about the intelligence capabilities of intelligent technologies were adapted from their naïve theories of biology, or whether children's beliefs were formed as a result of participating in a technology-rich cognitive ecology.

Results from the forced-choice task indicate a relationship between children's judgments of animacy and beliefs about the intelligence capabilities of robots. However, this relationship is mediated by children's level of prior exposure to robots. For children with little exposure to robots, animacy judgments were related to intelligence. Specifically, children who believed the robots were alive attributed a greater amount of intelligence to them than children who believed they were not alive. For children with higher levels of exposure to robots, there was less of a relationship between animacy judgments and intelligence. These children attributed similar amounts of intelligence to the robots regardless of whether they believed the robots were alive. Overall, children with high exposure attributed more intelligence to the robots than children with low exposure.

The fact that low exposure children attributed significantly more intelligence to robots when they believed they were alive suggests that for these children, ideas about intelligence may be part of a naive theory of biology. For high exposure children, ideas about intelligence seemed to exist independent of naïve biology. Perhaps based upon their exposure to robotic toys, movies, and books which portray robots as intelligent, these children are forming a concept of intelligence that supports beliefs about intelligence in inanimate entities.

Results from the justification questions paint a slightly different picture about children's use of biological knowledge to reason about the robots. When asked why they believed the entities were 'alive' or could 'think', children often used the same rationale to justify their responses to the robots and the biological entities. For example, children often cited movement as a justification for attributing life to both the biological entities and the robots. Children also cited the presence of a brain as a justification for attributing the ability to think to both the biological entities and robots. These findings suggest that children are using similar reasoning structures to support their beliefs about both robots and biological entities. Perhaps children are expanding some of their biological beliefs to robots, even while developing new ways to think about them.

Robots' unique combination of features make them difficult to classify. Most robots (including those used in this study) can move autonomously, but do not engage in biological processes such as growth or metabolism. The data from the current study suggests that most children are aware of these contradictory characteristics –over 80% of children said the humanoid robot and rover could move on their own, and less than 10% said the robots could grow or needed food or water. But which of these features are most influential to children when making animacy decisions? In this study, some children chose to focus on motion and declared the robots to be alive, while other children focused on a lack of biological processes or artifact construction and denied the robots animacy. In short, children do not seem to have a clear-cut understanding of how the term 'alive' applies to intelligent technologies, such as robots.

It is this type of finding, common in the literature, that has led Peter Kahn and colleagues to suggest that robots and other intelligent technologies may lead to the formation of a new ontological category (Friedman, Kahn, & Hagman, 2003; Kahn, Friedman, Perez-Granados & Freier, 2004; Melson, Kahn, Beck, Friedman, Roberts & Garrett, 2005). This proposed new category, which occupies a middle ground between animate and inanimate, may be better able to accommodate children's inconsistent judgments of robots as "alive" in a moral and cognitive sense, but not in a biological one.

My research suggests that something similar might be happening with intelligence. Children's ideas about the types of objects that can be intelligent are clearly changing as a result of living in a technology-rich culture. However, children may not be comfortable with a model of intelligence that exists completely independent of biological life. Just like children have held on to some of their notions of animacy while applying the term to intelligent technologies, they may hold on to some biological notions of intelligence even while applying their ideas to intelligent technologies. This situation could lead to a pattern of results where children were willing to attribute intelligence to inanimate entities, but still explained intelligence in biological terms.

Just as Sherry Turkle observed in 1984, our experiences with technology continue to challenge our beliefs about seemingly 'fundamental' notions, like what it means to be alive. As the cognitive ecology becomes increasingly filled with intelligent technologies, like robots, our ideas will be continually challenged and possibly refined. As Crowley and Jacobs (2002) suggest, ideas change on an everyday scale. Whenever an artifact in the environment piques a child's curiosity, the stage is set for learning. Every discovery has the potential to change a child's knowledge and beliefs. It is through an accumulation of these everyday moments that a child can develop an *island of expertise* in a domain of interest. This is one of the ways in which active participation in a cognitive ecology can lead to changes in knowledge, beliefs, and understanding.

While psychologists will continue to study children's reactions to robots in order to inform a set of narrowly defined research questions, the true phenomenon here is how basic concepts are being influenced, and possibly constructed, by children's participation in their everyday environments. The current research, along with the work of Sherry Turkle, Peter Kahn, and a few others, makes the bold statement that children's experiences in a technology-rich cognitive ecology are changing their beliefs about important things, like animacy and intelligence. This is the nature of the cohort effect – changes in the shared cognitive ecology will lead to changes in collective thinking. The ultimate goal of the current line of research is to predict the cognitive changes that are likely for children who participate in a culture of intelligent technologies.

One possibility for future research is to investigate the extent to which children see qualitative differences in the types of intelligence that exist in biological and non-biological entities. In the current study, children with prior exposure to robots rated the humanoid robot and the cat as having similar levels of intelligence. But do they believe these two entities are intelligent in the same way? Future research could investigate whether children are developing a separate category of intelligence for technology, or whether they believe intelligence looks the same across different types of entities.

Another potential direction for future research is to examine changes in children's beliefs about intelligence as a result of different types of exposure to robots. For example, will participating in the building and programming of robots yield different beliefs about robotic intelligence than watching science fiction accounts of intelligent robots? It is often the case that children who are interested in building robots also enjoy science fiction about robots. How do these children reconcile different sets of ideas about what robots are capable of?

APPENDIX A

FORCED-CHOICE TASK QUESTIONS

Biological Characteristics

Alive … Which cards have things on them that are alive?

Growth … Which cards have things on them that can grow? What I mean is, if we looked at these things a long time from now, they would be bigger?

Metabolism … Which cards have things on them that need food or water?

Movement … Which cards have things on them that can move by themselves?

Reproduction … Which cards have things on them that can make little ones just like themselves? Can make babies?

Psychological Characteristics

Emotion … Which cards have things on them that can feel happy or sad?

Volition … Which cards have things on them that if you gave them a choice, they could decide what to do?

Intelligence Characteristics

Calculate … Which cards have things on them that can add numbers together?

Learn … Which cards have things on them that can learn how to do new things?

Planning … Which cards have things on them that if we told them what to do, they could figure out how to do it?

Remember … Which cards have things on them that can remember things? Like if they did something today, they would remember it tomorrow?

Situational Awareness … Which cards have things on them that if we picked them up and put them in the room over there, they would know they were in a new place?

Think … Which cards have things on them that can think?

<u>Artifactual Processes</u>

Factory … Which cards have things on them that were made in a factory?

Put Together … Which cards have things on them that someone had to build?

APPENDIX B

PARENT SURVEY

1. Do you have any of the following in your house? (please check all that apply)
__ books about robots
__ videos about robots (educational)
__ videos with a lot of robots in them (e.g., Star Wars)
__ remote-control cars/toys

2. Has your child ever done any of the following? (please check all that apply)
__ visited a website about robots? (if so, which ones?___________________________)
__ visited a museum exhibit about robots?
__ attended robot camp? (if so, how long ago?____________)

3. Has your child ever built a robot? Yes No

If yes, approximately how many robots have they built?_________

How did they build them (e.g., using a robot construction kit, Lego Mindstorms, household construction materials, other materials)?
____

4. Does your child play with any of the following toys? (Please circle)
Bionicles   Lego Mindstorms   Lego Technic   Other robot-themed toys (please specify:________)

5. What are your child's favorite toys, books, and/or games?
____

6. How interested is your child in robots? (Please circle)

1	2	3	4	5	6	7
Not interested in playing with robots or learning more about them			**Plays with robots & has other interests**			**Prefers playing with robots or learning about them more than most other things**

7. How much does your child know about robots? (Please circle)

1	2	3	4	5	6	7
Can't name any robots/never built a robot			**knows about a few robots/has tried building robots (with help)**			**knows about lot of different robots/has built many robot**

8. How interested are you in robots? (Please circle)

1	**2**	**3**	**4**	**5**	**6**	**7**
I rarely seek out Information about robots			**I sometimes seek out information about robots**		**I seek out information about robots as often as I can**	

9. How much do you know about robots? (Please circle)

1	**2**	**3**	**4**	**5**	**6**	**7**
I can't name any robots, nor would I feel comfortable building a robot			**I can name a few robots, and I would feel a little comfortable building one**		**I know about a lot of robots, and I feel confident about building them**	

10. How much time per week does your child spend working on a computer? ____________

Please indicate which (if any) of these things your child does when they use the computer:

Play games   write programs   e-mail   use the Internet   Other

11. How interested is your child in computers? (Please circle)

1	**2**	**3**	**4**	**5**	**6**	**7**
Not interested in using the computer			**Enjoys doing specific things on the computer (e.g., playing games, e-mail)**		**Really loves the computer, and always wants to learn how to do new things on it**	

APPENDIX C

CORRELATION MATRICES

Humanoid Robot (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.269*	1													
Grow	.271*	.302*	1												
Eat	.181	.213	.245	1											
Move	.287*	.247	.103	.120	1										
Reproduce	.166	.210	.135	.288*	-.088	1									
Volition	.304*	.415**	.229	.267*	.268*	.098	1								
Calculate	.113	.365**	.215	.116	.299*	-.026	.401**	1							
Learn	.493**	.480**	.208	.107	.405**	.059	.503**	.497**	1						
Plan	.357**	.381**	.138	.161	.438**	.015	.452**	.267*	.439**	1					
Remember	.384**	.365**	.215	.116	.388**	-.026	.334**	.464**	.564**	.569**	1				
Situational Awareness	.292*	.292*	.175	.203	.495**	-.007	.346**	.397**	.285*	.636**	.536**	1			
Think	.207	.339**	.187	-.055	.274*	-.080	.272*	.259*	.492**	.354**	.464**	.367**	1		
Factory	.090	.203	.061	.071	.239	.105	.267*	.152	.295*	.443**	.286*	.213	.055	1	
Put Together	.157	.141	.043	.050	.166	-.200	.186	.199	.205	.098	.199	.244	.227	-.050	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

Rover (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.257*	1													
Grow	.143	.184	1												
Eat	.143	.184	-.053	1											
Move	.247	.293*	.103	.103	1										
Reproduce	.092	.267*	-.076	.178	.000	1									
Volition	.321*	.415**	.069	.222	.283*	.100	1								
Calculate	.328*	.554**	.245	.092	.329*	.022	.437**	1							
Learn	.484**	.509**	.076	.076	.447**	.222	.434**	.401**	1						
Plan	.098	.309*	.162	.162	.348**	.000	.377**	.307*	.354**	1					
Remember	.424**	.431**	.100	.100	.315*	.145	.406**	.497**	.570**	.569**	1				
Situational Awareness	.271*	.373**	.054	.208	.405**	-.034	.265*	.309*	.369**	.497**	.549**	1			
Think	.152	.258*	.039	-.116	.257*	-.056	.400**	.384**	.372**	.406**	.425**	.187	1		
Factory	.104	.197	.069	.069	.189	.101	.191	.282*	.181	.298*	.273*	.091	.112	1	
Put Together	.141	.122	.043	.043	.166	-.248	.192	.174	.186	.066	.168	.205	.220	-.056	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

Cat (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.	1													
Grow	.	.403**	1												
Eat	.	.487**	.432**	1											
Move	.	.	.	.											
Reproduce	.	.245	.484**	-.030	.	1									
Volition	.	.236	.298*	.184	.	.162	1								
Calculate	.	.089	.101	.043	.	.076	.236	1							
Learn	.	-.105	.059	-.051	.	.135	.243	-.033	1						
Plan	.	.292*	.227	.216	.	.208	.133	-.050	.096	1					
Remember	.	.236	.171	.184	.	.162	.250	.236	.035	.213	1				
Situational Awareness	.	.464**	.403**	-.035	.	.245	.378**	.089	.092	.292*	.236	1			
Think	.	.356**	.503**	.391**	.	.433**	.354**	.111	-.131	.302*	.471**	.356**	1		
Factory	.	.035	.039	.017	.	.030	.092	-.043	.051	.079	.092	.035	.043	1	
Put Together	.	-.111	.110	.047	.	.083	.147	.225	-.010	-.016	.257*	.097	.121	.358**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)
(correlation values could not be computed for questions where all children answered ‘yes’)

Person (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculation	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grow	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eat	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Move	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reproduce	.	.	.	.	.	1	.				.	.	.		
Volition	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Calculate	.	.	.	.	.	.248	.	1	.		.	.	.		
Learn	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plan	.	.	.	.	.	-.024	.	-.043	.	1	.	.	.		
Remember	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Situational Awareness	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Think	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Factory	.	.	.	.	.	.024	.	.043	.	.017	.	.	.	1	
Put Together	.	.	.	.	.	-.166	.	.149	.	.058	.	.	.	.291*	1

* Correlation is significant at the 0.05 level (2-tailed).
(correlation values could not be computed for questions where all children answered ‘yes’)

Computer (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	-.073	1													
Grow	.332*	-.024	1												
Eat	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Move	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reproduce	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Volition	-.074	.371**	.260*	.	.	.	1								
Compute	.100	.102	.072	.	.	.	.079	1							
Learn	-.059	.152	.275*	.	.	.	.517**	.160	1						
Plan	.139	.066	.184	.	.	.	.265*	.139	.487**	1					
Remember	.080	-.117	.207	.	.	.	.425**	.172	.371**	.418**	1				
Situational Awareness	.033	.248	-.043	.	.	.	.111	-.079	-.158	-.118	-.086	1			
Think	-.015	.098	.216	.	.	.	.358**	.154	.396**	.293*	.625**	-.075	1		
Factory	-.110	.078	.055	.	.	.	.093	.210	.199	.198	.264*	-.016	.253	1	
Put Together	.131	.062	.043	.	.	.	.167	.210	.158	.236	.210	.111	.201	.016	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
(correlation values could not be computed for questions where all children answered ‘no’)

Calculator (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion calculator	-.047	1													
Grow	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eat	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Move	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Reproduce	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Volition	.010	.332*	.	.	.	.	1								
Calculate	.097	.035	.	.	.	.	.105	1							
Learn	.010	-.051	.	.	.	.	.135	.105	1						
Plan	.045	-.072	.	.	.	.	.247	.147	.363**	1					
Remember	.284	-.055	.	.	.	.	.247	.112	.247	.541**	1				
Situational Awareness	-.097	.487**	.	.	.	.	.288*	.071	-.105	.011	.075	1			
Think	.078	-.065	.	.	.	.	.172	.134	.417**	.414**	.373**	.033	1		
Factory	.007	.055	.	.	.	.	.165	.449**	.165	.232	.176	-.075	.210	1	
Put Together	.163	.058	.	.	.	.	.175	.418**	.044	.141	.188	-.060	.224	.313**	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
(correlation values could not be computed for questions where all children answered ‘no’)

Plant (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.138	1													
Grow	.213	.089	1												
Eat	.302*	.076	.245	1											
Move	.175	.178	.061	.053	1										
Reproduce	.256*	.342**	.147	.127	.416**	1									
Volition	.016	.178	.061	.053	.298*	.416**	1								
Calculate	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Learn	.141	-.062	.050	.043	-.043	.117	.383**	.							
Plan	.141	-.062	.050	.043	-.043	-.102	-.043	.	.483**	1					
Remember	.099	-.043	.035	.030	.567**	.236	-.030	.	-.024	-.024	1				
Situational Awareness	-.109	.033	.105	.090	.135	.247	.585**	.	.200	-.073	-.051	1			
Think	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Factory	.061	.052	.097	.083	.155	.045	-.083	.	-.067	-.067	.358**	.010	.	1	
Put Together	.104	-.101	-.161	.069	-.069	-.166	-.069	.	.280*	.280*	-.039	.059	.	.266*	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
(correlation values could not be computed for questions where all children answered ‘no’)

Doll (N=60 for all cells)

	Alive	Emotion	Grow	Eat	Move	Reproduce	Volition	Calculate	Learn	Plan	Remember	Situational Awareness	Think	Factory	Put Together
Emotion	.393**	1													
Grow	-.030	-.047	1												
Eat	.567**	.358**	-.017	1											
Move	-.053	.393**	-.030	-.030	1										
Reproduce	.298*	.155	-.030	.567**	-.053	1									
Volition	.383**	.222	-.024	.701**	-.043	.383**	1								
Calculate	-.030	-.047	-.017	-.017	-.030	-.030	-.024	1							
Learn	-.030	.358**	-.017	-.017	.567**	-.030	-.024	-.017	1						
Plan	-.043	.222	-.024	-.024	.383**	-.043	-.034	-.024	.701**	1	.				
Remember	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Situational Awareness	.118	-.007	.310*	.310*	-.096	.118	.182	-.055	-.055	.182	.	1			
Think	-.043	.222	-.024	-.024	.383**	-.043	-.034	-.024	.701**	.483**	.	.182	1		
Factory	-.089	.038	.062	.062	.109	.109	-.152	-.275*	.062	.088	.	.078	.088	1	
Put Together	-.065	-.061	.068	.068	.121	.121	.098	-.248	.068	.098	.	-.006	-.128	.169	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
(correlation values could not be computed for questions where all children answered ‘no’)

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