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How do young children deal with hybrids of living and non-living things: The case of humanoid robots

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In this experiment, we tested children's intuitions about entities that bridge the contrast between living and non-living things. Three- and four-year-olds were asked to attribute a range of properties associated with living things and machines to novel category-defying complex artifacts (humanoid robots), a familiar living thing (a girl), and a familiar complex artifact (a camera). Results demonstrated that 4-year-olds tended to treat the category-defying entities like members of the inanimate group, while 3-year-olds showed more variability in their responding. This finding suggests that preschoolers' ability to classify complex artifacts that cross the living–non-living divide becomes more stable between the ages of 3 and 4 and that children at both ages draw on a range of properties when classifying such entities.

As children progress though early childhood, they elaborate their understanding of basic perceptual and behavioural differences between living and non-living things into an organized understanding of the correlational and causal structure of entities in these categories. This understanding may lay the foundation for children's thinking about the entities by allowing them to explain and predict their behaviour (e.g., Carey, 1985; Gelman, 2003; Gopnik & Nazzi, 2003; Keil, 1989; Opfer & Siegler, 2004). However, this knowledge will be most useful if children can classify an entity, and be confident that a range of inferences follows from the classification. Though this is often the case, there are exceptions, especially for novel entities that have characteristics of multiple categories. For example, bats look like birds (though they are mammals) and katydids look like leaves (though they are insects). Classic research investigating children's intuitions about such entities revealed that preschoolers can use category membership to understand such entities (Gelman & Markman, 1986).

However, there have been few investigations of hybrid items that include features of both living and non-living kinds. It is quite possible that this type of hybrid presents

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greater challenges to children because it violates an assumption about clear differences between living and non-living kinds. Examples of this sort of category-defying entity include complex intelligent artifacts, such as computers, and intelligent mechanical toys, such as robots. Robots represent an especially interesting test case: a robot might have to be turned on to operate, be rigid, and have mechanical insides, but at the same time, it might have a human form and be capable of self-initiated actions. These qualities make robots an obvious exemplar to use to investigate how children manage challenges to existing categorization schemes.

Previous research with infants suggests that they make a range of sophisticated inferences about such entities as they near their first birthday. For example in a classic study (Poulin-Dubois, Lepage, & Ferland, 1996), 12-month-old infants showed different emotional reactions to a radio-controlled robot that shared some features with a human (e.g., eyes, arms, self-movement) than to a person. In more recent work, researchers have shown that 9- and 10-month-old infants make predictions about the future actions of mechanical claws (Hofer, Hauf, & Aschersleben, 2005) and humanoid robots (Arita, Hiraki, Kanda, & Ishiguro, 2005). One interesting finding emerging from this work is that infants' predictions about entities' behaviours can be modified when they are given experience with the entity behaving intentionally. For example, in Arita *et al.* (2005) infants were surprised to see a person 'talk' to a robot, unless they had been given prior experience of the robot engaging in contingent interaction. The tendency to override initial classifications seems to be stable – toddlers will imitate the actions of a humanoid robot when the entity makes 'eye contact' with them (Itakura *et al.*, 2008). Recent work with adults suggests a similar finding – simply telling adults that a robot is intentional is not adequate to override the initial classification of the agents; like toddlers and infants, adults needed direct evidence of intentional behaviour (Levin, Saylor, Killingsworth, Gordon, & Kawamura, 2010).

Together this research suggests that as children emerge from the infancy period they distinguish robots from living things and make predictions about their behaviour that differ from the predictions they make about living things. However, the behaviour of complex entities can be made sense of in a variety of ways. Because children in the infant studies were not yet able to report on *which* properties they attribute to different entities, a question to investigate with older children is *how* they see robots as being the same as or different from living things. One possibility is that while young children see robots as being globally different from living things, they will still allow for the sharing of certain proprieties. An example from the categorization literature will illustrate how children's inferences about individual properties of entities may be in conflict with their global categorization judgments. Although children by the age of 5 are able to recognize that plants and animals share many important properties (like the capacity for growth and reproduction), and can sometimes classify plants with living things (Leddon, Waxman, & Medin, 2008), it is not until the age of 7 that children consistently recognize that plants are living things, like animals (Backscheider, Shatz, & Gelman, 1993; Hatano *et al.*, 1993; Inagaki & Hatano, 1996; Richards & Siegler, 1984; Springer & Keil, 1991).

The question of how preschoolers understand robots has been the focus of several studies (e.g., Carey, 1985; Freeman & Sera, 1996; Jipson & Gelman, 2007; Massey & Gelman, 1988; Mikropoulos, Misaildi, & Bonoti, 2003; Okita, Schwartz, Shibata, & Tokuda, 2007). In one early study, Freeman and Sera (1996) presented 3-, 4-, and 5-year-old children and adults with line drawings of entities possessing mixtures of biological and mechanical features (e.g., a telephone with a face, an outline of an animal face with mechanical parts). Participants were then asked to classify the entities as belonging to a machine or animal category and were asked whether the entities had a set of mechanical and biological properties. Their findings demonstrated that even 3-year-olds tended to classify these mixed entities as members of the machine category, but that children had poor explicit knowledge of the specific features that are typical of machines. For example, they were at chance in their responding about mechanical properties for familiar artifacts like telephones. Because their research question necessitated the use of unrealistic line drawings, an additional question is whether the Freeman and Sera findings would extend to children's inferences about more realistic depictions of category-defying entities. One possibility is that when children are faced with realistic depictions of entities that blend features of machines and living things, they will show some confusion about the entities.

A few recent studies have provided some additional insight. In one set of studies, researchers have revealed that preschoolers will sometimes attribute features of living things (e.g., thinking, being hungry) to more realistic versions of items that cross basic ontological distinctions (e.g., Melson *et al.*, 2005; Mikropoulos *et al.*, 2003; Okita *et al.*, 2007). All but one of these previous studies has used robots that resemble typical animals (like dogs) as their stimuli. For example, Okita *et al.* (2007) exposed preschoolers to several different types of robotic dogs. Their findings suggest that preschoolers attributed certain biological (e.g., being hungry) and psychological (e.g., remembering) properties associated with living things to the robotic dogs. The largest predictor of preschoolers' tendency to attribute psychological properties to the robots was their age (3-year-olds did so at higher levels than 4-year-olds). Jipson and Gelman (2007) also revealed developmental differences in preschoolers' treatment of robotic dogs. While 3- and 4-year-old children reliably differentiated the robotic dog from a real rodent with respect to biological properties (eating and growing), both age groups showed less reliable responding for psychological properties (thinking and feeling happy). Both of these previous studies have demonstrated that preschoolers will sometimes attribute features of living things to robots that resemble animals, but that they begin to make more reliable distinctions about animal robots at around 4 years of age.

While these previous studies provide a very clear picture of children's treatment of category-defying entities that possess some features that are shared with *animals* in general, there may be differences in how children understand entities that are more closely aligned with people. In particular, preschoolers' tendency to extend features typical of people (e.g., eating, sleeping, thinking) to other animals in induction tasks is related to the similarity of the animals to people. For example, they are more willing to extend features of living things from a person to a dog than a person to a worm (Carey, 1985; Gutheil, Vera, & Keil, 1998). There is also some indication that children will base their inductions of properties on physical similarities between animals, unless they are given information that allows them to override the tendency (e.g., if they are told the animals are kin, Springer, 1992). It is possible that this tendency may extend to entities that have physical resemblances with people as well (e.g., Epley, Waytz, & Cacioppo, 2007). This previous research suggests that children may make different inferences about robots that resemble people because of differences in the physical resemblance of the agents.

Humanoid robots may represent a special test case because they share a great deal of surface similarity with people – they have a human form and often possess facial features and can move in a way that mimics human movement. Therefore, they are particularly well suited to elicit a strong categorical response from children, especially with regard to agency. On one hand, this well-established category might enable children to recognize that humanoid robots, though sharing surface similarities to people do not share deeper underlying similarity. This recognition would be revealed by a tendency to treat such entities as machines. On the other hand, the surface similarity of humanoid robots to humans may make the differentiation between people and robots more difficult for preschoolers. Because children's understanding of these basic distinctions is developing during the preschool period it is possible that younger preschoolers may experience challenges with entities that crosscut category boundaries because of weak domain understanding.

Consistent with this second possibility, Mikropoulos *et al.* (2003) suggest that there are developmental differences in preschoolers' tendency to attribute features of living things, including internal features (having a brain and heart), mental states (knowing things and wanting to do things), and life status (being alive) to humanoid robots. In their study, 3- and 4-year-old children were likely to attribute (95 and 68% 'Yes' responses across the group of questions for each age group) such properties to a robot, while 5-year-olds were not (42% 'Yes' responses). Children were also asked about a computer (73, 43, 16% 'Yes' responses for 3-, 4-, and 5-year-olds, respectively) and a person (95, 98, 99% 'Yes' responses). It is not clear from Mikropoulos *et al.*'s statistical analyses whether children's responding to the robot was different from the computer and person at each age group (because they only report differences in mean levels of responding collapsed across age). This analysis would be important to answer the question of whether children's tendency to equate the robot with the other entities changes across development. Relatedly, Mikropoulos *et al.* did not ask about mechanical properties, so there is some question about how the humanoid robot was being treated relative to the other artifact included in the study. One possibility is that children would be willing to attribute properties of living things *and* machines to the robot because of it shares features with members of both categories, but would only tend to attribute features of machines to the other entity. In addition, because Mikropoulos *et al.* (2003) only asked about properties that elicited a 'Yes' response for the person they may have set up a response bias in their youngest group of participants. Finally, children were shown a video of the robot and the person, but were shown a 'computer program' on a real computer, making any differences in children's responding to the computer versus the other entities difficult to interpret.

The current study addressed these issues by asking 3- and 4-year-old's to attribute a set attributes typically associated with living things and a set of attributes typically associated with machines to two category-defying complex artifacts (robots), a familiar living thing (a girl), and a familiar complex artifact (camera). If children attributed the properties at different levels to the robots than the other entities, we saw this as evidence of children placing the entities in different categories. On the other hand, if children failed to attribute properties to the entities at different levels, we took this as evidence that they grouped the entities together.

Children were also asked to explain their attributions to investigate whether they differentiated between the living things and artifacts with their explanations. Our predictions were that such differentiation would be shown by children being more likely to mention the category label or internal features of the entities for the girl than artifacts. Previous research has revealed that category labels and internal features are related to children's tendency to essentialize living things (see Gelman, 2004, for discussion). We also predicted that children would be more likely to mention the origins of an entity for the girl than artifacts. On the other hand, we hypothesized that children would tend to cite how an entity is used, the consequences of having or not having a feature, and the external features of an entity or property when justifying responses for artifacts. There is some indication from previous work that artifacts are classified according to their intended function and form (see, e.g., Gutheil, Bloom, Valderrama, & Freedman, 2004).

Method

Participants

Participants were 36 children divided into two age groups: 14 three-year-olds (range: 3; 4 to 4; 1, mean age = 3; 10, 6 females, 8 males) and 22 four-year-olds (range: 4; 6 to 5; 0, mean age = 4; 8, 11 females, 11 males). Children were primarily from upper to middle class families and were recruited from a database of parents interested in research participation. An additional 7 children participated, but their data were not included because of non-compliance (2 three-year-olds, 1 four-year-old) and failure to complete the task (4 three-year-olds).

Materials

Each child was presented with two warm up pictures and four target pictures. The pictures were presented on 4×8 in. laminated index cards. The two training pictures were a red square and a yellow duck. The four target pictures included a familiar living thing (a preschool-aged girl wearing a yellow dress), a familiar complex artifact (a Canon digital video-camera), and two novel category-defying complex artifacts (Intelligent Soft-Arm Control, ISAC, a humanoid robot designed by Kawamura, Bagchi, Iskarous, Bishay, and Peters (1995), and Sony's humanoid Qrio). The pictures of the girl, camera, and Qrio were retrieved from the Internet. A publicity photo of ISAC was used for the study. The robots were chosen on the basis of their humanoid form – both ISAC and Qrio have clear arms, a head, eyes, and a torso. Preliminary analysis using McNemar's change tests were conducted separately by age to compare children's responding on individual items across the two robots, revealed no differences in children's responding (all ps $> .25$ for 3-year-olds, ps $> .22$ for 4-year-olds), so we collapsed responding to the two robots in the analyses below (individual data for ISAC and Qrio are presented in the Appendix). The camera was chosen because it is a complex artifact that children are familiar with and was a fairer comparison object to the robot (because they share some features, including an ability to 'represent' information in the environment, and the need to be turned on to work) than a more canonical non-living thing (e.g., a rock). The pictures of the entities were presented against a white background.

Children were asked nine questions about each target item. Five of the questions were about properties typically associated with living things (seeing, thinking, thinking about what you see, being born, being alive) and four were about properties associated with machines (construction with tools, having wires inside, turning on, being kept in a closet). Preliminary analyses revealed that children did not understand the closet question. We did not want to underestimate children's knowledge of mechanical properties by including a question they clearly did not understand (this question had also not been used in previous studies) so we removed the question from analysis. All items were referred to with basic level labels (i.e., girl, camera, robot). Each question was printed on a laminated index card. See Table 1 for list of specific questions used.

Table 1. Test questions: Basic level name (girl, camera, robot) was inserted into the blank

Question type	
Living things	If you held a banana in front of this ____, could this _____ see the banana?
	Can this ____ think?
	If you held a cup in front of this ____, could this ____ think about the cup?
	Was this ____ born?
	Is this ____ alive?
Mechanical	Do you need tools to put this ____ together?
	Does this ____ have wires inside?
	Can you turn this ____ on?

Equipment
All sessions were video recorded.

Procedure and design
Children met with two experimenters during a session that lasted approximately 30 min. One experimenter (E1) showed children the pictures and asked them the test questions, while the other (E2) recorded their responses. Children sat at a table across from E1, and E2 sat behind them. During the session, parents filled out a questionnaire.

The session began with E1 telling children that she would show them pictures that she took the day before and ask about the things in the pictures. Children were told that sometimes the answer would be yes, and sometimes the answer would be no, but that it was okay to say 'I don't know'. The session was divided into three phases: warm-up, label comprehension, and test.

The *warm-up phase* was designed to ensure that children realized that sometimes answers would be 'yes' and sometimes answers would be 'no'. During the warm-up phase, children were shown the picture of the red square and the yellow duck, one at a time. They were asked two questions about each item, one that would elicit a yes answer (e.g., 'Is this a square?') and one that would elicit a no answer (e.g., 'Is this square blue?'). Children were always asked about the square first. All children answered these questions correctly.

Pilot data revealed that preschoolers were able to produce the labels for the camera and girl at ceiling levels, but that they showed more variability in their labelling of the robots. For this reason, the main focus of the *label comprehension phase* was children's comprehension of the label 'robot'. E1 placed all four target pictures on the table and asked children to point to the robots (i.e., 'Show me the robot. Is there another one?'). If children did not identify the robots, E1 would point to the item and repeat the appropriate label (e.g., 'This one is a robot') and ask children to identify the robots again. This occurred for 4 four-year-olds and 1 three-year-old, but all 5 children correctly identified the robot after her second prompt. Children were then asked to identify the camera and the girl. All children were able to do so. The test pictures were then picked up and the *test phase* began.

During the *test phase*, we asked whether children would attribute properties associated with living things and machines to the items. The test phase began with E1 placing the picture of one item (e.g., the girl) on the table and asking a test question (e.g., 'Does this girl think?'). After each question, E1 asked children to explain their answer by asking 'Why?' or 'How do you know?' If children were non-responsive to the explanation prompt, E1 asked them for more information (e.g., by saying, 'Why can't this girl think?'). The researcher repeated the prompt up to two times. If children failed to offer more information after the additional prompt, the researcher moved on to the next question. After the child explained their answer they were asked the next test question (e.g., 'Does this girl have wires inside?'). This was repeated for each of the nine test questions. After completing the test questions for one item, E1 placed the picture of the next item (e.g., ISAC) on the table and repeated the test questions and explanation prompts for that item.

E1 determined order of presentation by first shuffling pictures to randomize item order with the end result being that each test item appeared first about equally often, and then shuffling question cards to randomize question order. Question order was randomized for each test item (that is, E1 shuffled the question cards for each item). This way, item order and question order were randomized across children.

Coding

For each test question, children were given 1 point for 'Yes' responses and 0 points for 'No' responses. If children offered no response to a question or said, 'I don't know', the trial was omitted. Because 8 children failed to answer one or more test questions (18 of 1,152 possible responses or 1.6% of the total), children's scores for each domain are presented as the percentage of yes responses to each question type.

Children's explanations were divided into five categories: kind, internal features, origins, external features, functions. The first three categories were predicted to be more common for the girl than the camera or robots. Children's explanations were coded as falling into the kind category if they offered the basic category label of the entity (e.g., 'Cause it's just a robot', 'Because she's not a tv'.) or life status (e.g., 'because she's alive') of the entity as a justification. Internal features explanations included mention of stuff on the inside of the entity. Origins explanations included mention of where the entity came from, this included both biological origins (e.g., 'because she was born') and non-biological origins (e.g., 'cause she's already put together', 'because God made it'). The last two categories were predicted to be more common for the robots and camera than the girl. External features explanations included mention of the surface features (e.g., 'cause she has eyes', 'because it has the turn on thing') or size (e.g., 'because he was just little') of an entity. Function explanations included mention of the what the entity was used for (e.g., 'because it takes pictures') or the consequences of having or not having an attribute (e.g., 'because it will break'). All other explanations were classified as other, and will not be discussed further. Because children did not always offer an explanation (e.g., if they failed to answer the initial question) percentage scores were generated for the explanations. A second coder who was blind to the experimental predictions independently coded the explanations from six participants. She agreed with the main coder 88% of the time (Cohen's $\kappa = .83$). The first coder's judgments were used in the analyses below.

Results

Our primary question was whether children treated the novel category-defying entities the same as the familiar entities. To investigate this, we compared the overall levels of attributions within each question type (living thing, machine) across entity (girl, camera, and robots) using a mixed MANOVA. Following these analyses of primary interest, we investigate the children's individual patterns of responding and their explanations for their responses.

Because of our interest in developmental differences in children's responding, we conducted planned comparisons of children's responding to the three entities separately by age, even when interactions were not significant. We examine these with an analysis of simple effects in MANOVA by comparing children's level of attributions within each question type across entity. Our reasoning was that if children categorized the entities as the same kind of thing they should be equally likely to attribute properties to them. A tendency to treat the robots as mechanical entities like the camera would be revealed by responding to the robot being different from the girl, but the same as the camera. In conducting these simple effects analyses, we used Bonferroni adjustments for multiple comparisons. See Figure 1 for a summary of these results.

The proportion of yes responses to our test questions about living things and machines was entered into a 3 (entity: girl, robots, camera) × 2 (age: 3-year-old, 4-year-old) mixed MANOVA. Entity was a within-subjects variable and age was a between-subjects variable. The MANOVA revealed a main effect of Entity, $F(4,31) = 46.83$, $p < .001$, $h_p^2 = .86$. Univariate tests revealed the effect of entity was present for the living thing ($F(2,68) = 57.40$, $p < .001$, $h_p^2 = .63$) and machine

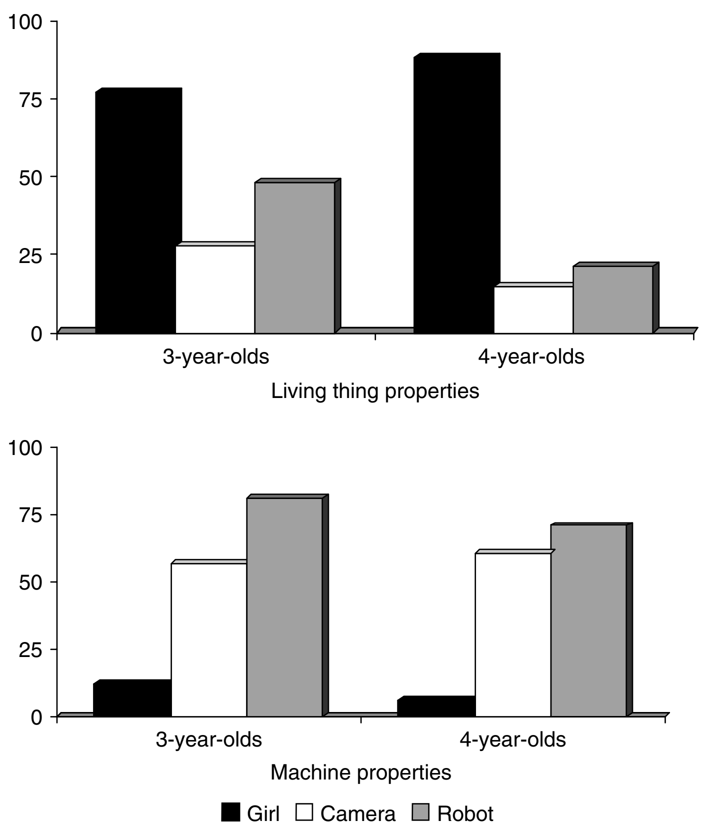

Figure 1. Mean percentage of property attributions as a function of entity and age.

($F(2, 68) = 51.75, p < .001, h_p^2 = .60$) test questions. The omnibus tests did not reveal a main effect of Age ($F(2, 33) = 1.31$, $p = .28$, $h_p^2 = .07$) or an Age × Entity interaction ($F(2, 68) = 2.00, p = .12, h_p^2 = .20$). Univariate tests confirmed the lack of an age effect for the two types of test questions, but revealed a significant Age × Entity interaction for questions about properties of living things, $F(2, 68) = 4.82$, $p = .01$, $h_p^2 = .12$.

Both 3- and 4-year-olds differentiated between the familiar entities by attributing more of properties of living things to the girl than the camera (paired samples ts ≥ 5.05, ps $< .001$) and robots (paired samples ts ≥ 2.67, ps $< .03$) and more properties of machines to the camera (paired samples ts ≥ 5.05, 3.83, ps $< .002$) and robots (paired samples ts > 6.11, ps $< .001$) than girl. However, 4-year-olds treated the robot and camera the same for both properties of living things and machines (paired samples ts ≤ 1.40, ps $> .51$), while 3-year-olds differentiated between the cameras and robots (paired samples ts ≥ 2.76, ps $< .03$). In particular, they attributed more properties of living things and machines to the robots than the camera.

Analysis of individual patterns of responding

The analyses above suggest that as children age, they begin to treat the category-defying entities similarly to how they treat a familiar inanimate object. This pattern is suggestive of children beginning to form a category of machines that includes both types of entities. To further investigate this possibility, individual children were categorized as treating an entity as a living thing, machine, or other. The criteria for being classified as treating an entity as a *living thing* was that the child give yes responses to two-thirds or more of the questions about properties of living things *and* no responses to two-thirds or more of the questions about properties of machines. The criteria for being classified as treating an entity as a *machine* was the inverse of the living thing pattern. All other patterns were classified as other. See Table 2 for frequency of response types.

Table 2. Children's tendency to classify each entity as a living thing, machine, or other by age

	Living thing	Machine	Other
Girl			
3-year-olds	64% (9 of 14)	0	36% (5 of 14)
4-year-olds	82% (18 of 22)	0	18% (4 of 22)
Camera			
3-year-olds	0	36% (5 of 14)	65% (9 of 14)
4-year-olds	5% (1 of 22)	55% (12 of 22)	41% (9 of 22)
Robots			
3-year-olds	7% (1 of 14)	7% (1 of 14)	86% (12 of 14)
4-year-olds	0	59% (13 of 22)	41% (9 of 22)

The *other* category included responses that were high levels of yes responses to both living thing and machine questions (11 of 48 other responses, 23%), attributing less than one property of each type (20 of 48 other responses, 42%), and patterns that missed classification into living thing and machine categories (17 of 48 other responses, 35%). There were no differences in the distribution of other responses across age groups within each entity.

Analysis of the individual patterns of responding using a chi-squared test-of-association, revealed that children's tendency to treat the familiar entities as a living thing, machine, or other did not differ across age groups, $\chi^2(2) \leq 1.60$, ns. Children at both age groups tended to treat the girl as a *living thing* (75%, 27 out of 36 children), and the camera as either a *machine* (47%, 17 out of 27 children) or *other* (58%, 18 out of 27 children).

A chi-squared test-of-association revealed different patterns of responding for the two age groups for children's responding to the robots, $\chi^2(2) = 10.45$. $p = .005$. An analysis of the patterns at each age group revealed that 3-year-olds were more likely to classify the robot as *other* (87%, 12 of 14 of children) than 4-year-olds (41%, 9 of 22 children) and 4-year-olds were more likely to classify the robot as a *machine* (59%, 13 of 22) than 3-year-olds (7% or 1 of 14). A follow-up 2×2 chi-squared test-of-association on children's tendency to classify the robot as a machine or other revealed a significant difference in the patterns seen across age groups, $\chi^2(1) = 8.99$, $p = .003$. This analysis is consistent with older children being more likely to classify the robot as a machine than younger children. There was also some indication from children's individual patterns of responding that there was a relationship between how children classified the robots and the camera. In particular, children who classified the robot as a machine also classified the camera as a machine (79% or 11 of 14 children), and children who classified the robot as other also classified the camera as other (71%, 15 of 21 children).

Individual items

As a second step in characterizing children's responding, we investigated the reliability of children's level of attribution of the individual items using two-tailed binomial tests (for the girl and camera) and one-sample *t* tests (for the robots). Each age group was analysed separately for these analyses. Unless otherwise noted, children's responding was in the direction predicted by category membership (see Table 3).

Table 3. Percentage of yes responses to individual items for the girl, camera, and robots by age

	Properties							
	Living thing					Mechanical		
Items	See	Think	See–Think	Born	Alive	Tools	On	Wires
Girl								
3-year-olds	79	100	79	85	64	29	8	14
4-year-olds	100	91	75	86	86	5	9	5
Camera								
3-year-olds	36	31	36	29	15	64	71	36
4-year-olds	24	14	14	5	23	57	81	50
Robots								
3-year-olds	50	61	54	31	35	82	75	86
4-year-olds	41	16	14	2	34	76	69	66

Four-year-olds revealed reliable responding for all questions about the girl (all ps $< .04$) except for the see–think question which just missed being different from chance ($p = .05$). The older children also revealed reliable responding for all but two of the questions about the camera (all ps $< .05$). Their responding to the questions about needing tools to put the camera together and the camera having wires inside was at chance. Four-year-olds' responding to questions about the robot differed from chance levels in the predicted directions for the questions about thinking, thinking about what is seen, being born, and needing tools for assembly (one-sample $t\text{s}(21) \geq 2.66$, $p\text{s} < .05$). The question about being turned on just missed standard significance levels (one-sample $t(20) = 2.02$, $p = .06$). The questions about seeing, being alive, and having wires inside were at chance (one-sample $t\text{s}(21) \leq 1.67$, $p \geq .11$).

For the girl, 3-year-olds' responding was less reliable overall. Their responding differed from chance at standard significance levels ($p < .05$ by a binomial test) for the think, born, turn on, and wires questions, and just missed the standard levels ($p = .06$ by a binomial test) for the see and see–think questions. Three-year-olds' responding to questions about the girl being alive and requiring tools to be assembled did not differ from chance levels. Responding was more variable still for the camera and robot. The number of children who offered responses in the predicted direction only differed from chance levels for the questions about the camera being alive ($p < .05$ by a binomial test), the robot requiring tools for assembly, being turned on, and having wires inside (one-sample $t\text{s}(21) \geq 2.82$, $p \leq .01$). All other items were at chance levels.

For both age groups, responding was most reliable for the girl. Four-year-olds also revealed a distinction between the familiar entities (as responding on most of the items was different from chance) and the robot (for which they showed less reliable responding). Three-year-olds failed to show reliable responding for the majority of items for both the robot and camera.

Explanation data

One additional question concerns the nature of children's explanations for their attributions of features to the three entities. A series of mixed repeated measures ANOVAs with entity as the within subjects variable and age group as the between subjects variable were used to investigate our predictions. Planned comparisons were used to investigate significant main effects. Bonferroni adjustments for multiple comparisons were used for planned comparisons. See Table 4 for a summary of these results.

Three explanation types were predicted to be more common for the girl than camera or robots: mention of kind, origins, and internal features. The analyses revealed a main effect of entity for kind explanations, $F(2, 70) = 3.86$, $p = .03$. $h_p^2 = .10$.

Table 4. Percentage of explanations in by entity and age group

	Kind	Origins	Insides	Function	External	Other
Girl						
3-year-olds	19	9	4	11	11	45
4-year-olds	31	9	13	8	14	28
Camera						
3-year-olds	15	6	5	9	17	50
4-year-olds	17	12	18	15	20	24
Robots						
3-year-olds	20	5	3	9	23	44
4-year-olds	24	7	15	14	19	25

Planned comparisons revealed that children were more likely to offer kind explanations for the girl than the camera, paired-samples $t(34) = 3.00$, $p = .02$. In addition, there was a main effect of age for the internal features explanation type with 4-year-olds being more likely to mention internal features than 3-year-olds, $F(1, 35) = 9.24$, $p = .004$. $h_p^2 = .21$. There were no other significant effects for the kind, origins, and internal features explanation types.

Children were predicted to be more likely to mention external features, functions of an entity for the robots and camera than girl. The external features explanation type revealed a main effect of entity, $F(2, 70) = 7.06$, $p = .002$. $h_p^2 = .17$, that was the result of children offering more external features explanations for the robot than girl, paired-samples $t(34) = 4.00$, $p = .001$. There was also a trend for children to offer more external features explanations for the camera than the girl, paired-samples $t(34) = 2.29$, $p = .09$. There were no other significant effects.

Discussion

In this research, we investigated preschoolers' categorization of entities that contain features of living and non-living things by asking them to attribute a range of properties typical of living things and machines to humanoid robots. Because humanoid robots blend features of living and non-living things they represent and interesting test bed for questions about the nature of children's categorization when they face challenges to their existing category structure. Previous research on children's understanding of humanoid robots left several questions about preschool children's treatment of the entities (Mikropoulos *et al.*, 2003). The current study clarifies these issues by providing information about developmental differences in children's categorization of robots relative to familiar entities, and by providing information about preschoolers' attributions of mechanical attributes to the entities.

The findings suggest that 3- and 4-year-old children differentiated between girl and robots and girl and camera. In particular, both age groups were more likely to attribute properties of living things to the girl than camera or robots, and were more likely to attribute features of machines to the camera and robots than girl. Differences across age groups emerged in children's responding to the robots and camera. In particular, 4-year-olds treated the robot and camera the same for properties of living things and machines, while 3-year-olds attributed more properties of living things and machines to the robot than the camera. In addition, 4-year-olds were more likely to classify the robot as a machine (as shown by individual patterns of responding) than 3-year-olds. The group of children who classified the robot as a machine were also likely to classify the camera as a machine. This is suggestive evidence that they have begun to group the entities together as the same kind of thing.

However, this understanding is clearly still emerging in the age ranges investigated in the present study. For one, neither age group was reliable at the individual level for more than half of the questions about the robots. In addition, while both 3- and 4-year-olds were able to correctly reject mechanical properties as being characteristics of the living thing, both age groups were largely unreliable in their responding to the individual questions about mechanical properties of the camera. On the other hand, both age groups revealed more reliable responding for mechanical properties of the robot. Three-year-olds' responding for mechanical properties was different from chance for all three of the properties they were asked about and 4-year-olds revealed reliable responding for one the attributes, and just missed standard significance levels for a second. What might account for this difference in responding to the two artifacts? It is possible that their relative levels of experience with different artifacts influenced their attributions of individual properties. Because cameras are household objects that they are probably not able to touch or play with, they may have been less likely to say that the camera could be turned on (because they are not allowed to do it) or that put together (because they see cameras being bought in the store). This kind of explicit knowledge may not be available for the less familiar robots. Future research should address these possibilities.

Children also showed some tendency to differentiate between the entities with their explanations. In particular, they offered more kind explanations for the girl than camera, and more external features explanations for the robot than girl and were trending to offer more external features explanations for the camera than girl. These findings are consistent with children attending to different features when justifying their responses.

It is important to note that our analysis grouped both psychological and biological properties of living things together. We did this because we wanted to focus on childrens' general tendency to group the novel entity with either the familiar living thing, or the familiar non-living thing, Clearly, a more specific analysis, perhaps distinguishing psychological and biological properties, might further clarify the frameworks that children apply to novel ambiguous entities. However, because of our general focus, a more specific analysis would be underpowered and overly complex, especially given the large number of higher order interactions it would involve. Therefore, we leave this to future research in which more questions about psychological and biological properties can be added, and more specific *a priori* predictions can guide the analysis.

Developmental implications

Previous research from infants suggests that they distinguish robots from living things and make predictions about their behaviour that differ from the predictions they make about living things. The present study provides information about the basis on which children might make this classification, by clarifying that young preschool children treat robots as being somewhere between familiar living and non-living things for properties of living things. At the same time, they were willing to attribute higher levels of mechanical properties humanoid robots than to familiar living things. The tendency to provide an intermediate classification appears to diminish as children age.

One remaining question concerns what evidence might affect children's analysis of category-defying complex artifacts. A recent study suggests that even older preschoolers remain sensitive to attempts to anthropomorphize robots. In particular, 4- and 5-year-old children saw live robot (instead of a video) that looked like a living thing and appeared to produce goal-directed behaviour (by approaching and hitting several balls seemingly on its own). Both age groups were willing to attribute certain properties of living things to the entity (seeing, thinking, counting, and remembering). However, both 4- and 5-year-olds lessened their attributions of properties of living things after begin given evidence that the robot was controlled with a remote or if it no longer resembled a living thing (Somanader, Saylor, & Levin, 2007). This research points to a flexible and context sensitive classification of complex artifacts like robots.

One question is what might affect children's tendency to use evidence of mechanical or anthropomorphic behaviour to revise their classification of robots. Increased contact with category-defying complex artifacts across development could result in at least two outcomes. On one hand, initial flexibility in categorization of the entities may be lost.

One reason may be that as children have increased contact with these artifacts they learn about their limitations as living agents and their status as machines. On the other hand, flexibility in the categorization of such entities may persist throughout the life-span. In this case, when given adequate evidence of a commonality with a living entity, even adults may sometimes say that complex artifacts share features with living things. On this view, observers' requirements for adequate evidence may be changing across development.

Recent work with adults has supported the latter of these two possibilities. In one study, adults were asked to make predictions about the behaviour of living things (people), clear hybrids (robots), and artifacts that were more clearly non-living (computers). Although adults, like older preschoolers, initially treated the hybrids as machines (by equating them with the computer) they overcame this tendency when given evidence that robots were attending to objects. Interestingly, simply telling adults that the robot was intentional was not adequate to override the initial classification of the agents; like preschoolers, adults needed direct evidence of intentional behaviour (Levin *et al.*, 2010). One additional commonality seen in the behaviour of adults and older preschoolers is that neither group equated robots with humans. Preschoolers' attributions of properties of living things of robots did not reach the level attained for a person, and adults did not equate humans and robots, even when the robot was to be built-in the future or was fully controlled by a human (Levin, Killingsworth, & Saylor, 2008). Together these studies suggest that an initial tendency to categorize complex artifacts as machines can be overridden with supporting evidence, and suggest that the categorization of category-defying complex artifacts continues to be flexible and dynamic throughout the life-span.

Will children's classification of robots generalize?

An additional question concerns the generalizability of these findings. There is some indication that our findings dovetail with those of previous studies that investigated children's categorization of category-defying complex artifacts, including robotic dogs and humanoid robots (e.g., Jipson & Gelman, 2007; Mikropoulos *et al.*, 2003; Okita *et al.*, 2007) in younger children's tendency to attribute properties of living things to the entities. This would suggest that an initial tendency to attribute both properties of living things and machines to robots would apply generally to category members. In addition, the two humanoid robots we included yielded similar responding from the children. Even still, a challenge for future work will be to investigate whether such attributions will generalize across robots that take different forms. Based on our findings, our prediction would be that younger children would fail to generalize properties to new exemplars (because their understanding of such artifacts is still emerging) and that properties may not generalize across robots that do not share surface features or behaviour. One interesting implication here is that children may not take an essentialist view of category-defying complex artifacts, as their categorization of such entities varies by context and is related to surface features rather than underlying similarity (e.g., Sloman & Malt, 2003).

Summary

Taken together, this research suggests that children's ability to offer an appropriate domain consistent categorization of category-defying complex artifacts emerges around age 4. Together with previous studies, this work adds to an emerging picture of children's categorization of complex artifacts as being flexible and context dependent. This makes sense when viewed in light of the nature of these entities – they are constructed, have a variety of potential functions and may not have essential features like girls and trees. However, it interesting to consider the degree to which the increasing prevalence of mixed entities may affect more basic understandings of living and non-living things. Will children (and adults) change the inferences that they make when dealing even with familiar living and non-living things? It is possible that these challenges will make learning and using basic categories more difficult, but it is also possible that people will respond with a more sophisticated understanding of living and non-living things. Indeed, given the large number of children and adults happily interacting with each other and with artificial agents in mediated electronic environments, it would seem changes may already be occurring, and it may be our job simply to keep up.

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Appendix

Percentage of children at each age offering yes responses to individual items for ISAC and Qrio

	Properties							
	Living thing					Mechanical		
Items	See	Think	See–Think	Born	Alive	Tools	On	Wires
Qrio								
3-year-olds	43	54	42	42	38	79	71	85
4-year-olds	32	14	10	5	33	73	68	71
ISAC								
3-year-olds	57	36	67	23	31	86	92	85
4-year-olds	50	18	19	0	32	76	67	59