You Get What You Need: An Examination of Purpose-Based Inheritance Reasoning in Undergraduates, Preschoolers, and Biological Experts

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Abstract

This set of seven experiments examines reasoning about the inheritance and acquisition of physical properties in preschoolers, undergraduates, and biology experts. Participants ($N = 390$) received adoption vignettes in which a baby animal was born to one parent but raised by a biologically unrelated parent, and they judged whether the offspring would have the same property as the birth or rearing parent. For each vignette, the animal parents had contrasting values on a physical property dimension (e.g., the birth parent had a short tail; the rearing parent had a long tail). Depending on the condition, the distinct properties had distinct functions ("function-predictive") were associated with distinct habitats ("habitat-predictive"), or had no implications ("non-predictive"). Undergraduates' bias to view properties as inherited from the birth parent was reduced in the function- and habitat-predictive conditions. This result indicates a purpose-based view of inheritance, whereby animals can acquire properties that serve a purpose in their environment. This stance was not found in experts or preschoolers. We discuss the results in terms of how undergraduates' purpose-based inheritance reasoning develops and relates to larger-scale misconceptions about Darwinian evolutionary processes, and implications for biology education.

Keywords: Conceptual development; Naïve theories; Evolution; Science education; Teleology

1. You get what you need: Purpose-based reasoning guides undergraduates' inheritance judgments

Understanding the processes that underlie biological inheritance is a critical cognitive achievement with important policy implications. Knowing which properties are inherited, which are not, and how these processes unfold is critical for making inferences about the

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natural world. From an educational standpoint, an understanding of inheritance is an important component of Darwin's theory of evolution, a framework that unifies and forms the foundation for modern biology. From a policy standpoint, knowledge of inheritance contributes to our understanding of the biological versus social basis of categories such as race or gender, helps us to understand how diseases are transmitted and thus determine healthy practices, and promotes scientific literacy on topics such as the Human Genome Project.

Given the importance of understanding the processes involved in inheritance, it is also important to determine the nature of lay beliefs about inheritance and how they emerge and change with maturation and experience. There are two primary bodies of prior research on this topic—one originating from the field of science education, and the other from the field of cognitive development. The science education research has focused on asking whether students' concepts of evolutionary change are consistent with modern evolutionary theory (Gregory, 2009). According to the Darwinian model, properties evolve within a species as a result of gene recombination and chance mutations that lead to individual variation within the species. This results in a range of traits that vary in their capacity to promote survival and reproduction. Traits with such advantages are more likely to be passed onto the next generation and retained within the species. Despite the universal acceptance of this model within the scientific community, fundamental concepts of evolution are notoriously misunderstood. Students in all grade levels have a variety of misconceptions about evolutionary processes, including populations that one would assume to have more expertise, such as undergraduate biology majors and pre-med students (e.g., Bishop & Anderson, 1990; Brumby, 1979, 1984; Deadman & Kelly, 1978; Demastes, Settlage, & Good, 1995; Greene, 1990; Jensen & Finley, 1995, 1996; Settlage, 1994; Shtulman, 2006). For example, a common misconception is that properties within a species are acquired as needed (e.g., that the ability to run fast evolved within the cheetah species because they needed to be able to run fast in order to catch food), rather than through a process of individual variation and perpetuation of those properties that promote survival. Another common misconception involves confusing the process of heritable changes increasing within a population over time with the acquisition of non-inherited changes during an individual organism's lifetime. Specifically, students frequently make the mistake of thinking that changes acquired within an organism's lifetime can be passed onto offspring and lead to change within a species (Brumby, 1979; Ferrari & Chi, 1998; Greene, 1990; Jensen & Finley, 1996). This is referred to as "Lamarckian" reasoning (or "soft inheritance") because Lamarck—and other biologists before him—thought inheritance of acquired traits to be a key mechanism in evolution.

Related research in the field of cognitive development has focused on examining the conceptual frameworks underlying naïve theories of inheritance. In one paradigm, participants are asked whether a baby animal will be like its biological parent or some other animal, on a particular property dimension. Using this procedure, researchers have discovered that knowledge of inheritance emerges well before formal schooling (Gelman & Wellman, 1991; Springer, 1992). For example, 4 year olds correctly use kinship over

perceptual similarity or friendship as a basis for inferring a baby animal's physical properties (Springer, 1992). Preschoolers also use kinship selectively for inferences about biological properties (e.g., has tiny bones inside) and not for non-biological properties (e.g., likes to go camping; Springer, 1996). Thus, an awareness that only certain types of properties are predictably inherited from biological parents to their offspring emerges early, but also undergoes significant development during the preschool years (Heyman & Gelman, 2000; Johnson & Solomon, 1997; Solomon, Johnson, Zaitchik, & Carey, 1996; Williams & Smith, 2010).

The current studies focus on judgments about the heritability of properties that have *functional implications* for an animal. The significance of functions in novice biological reasoning is well established. For instance, high school students and undergraduates find teleological explanations for how organisms come to possess certain features to be acceptable (e.g., white bears developed thick fur *in order to* protect themselves from low temperatures in arctic climates; Jensen & Finley, 1996; Tamir & Zohar, 1991). In this reasoning framework, the function of the property is considered a sufficient causal mechanism for the property's emergence within a species. Another variant of teleological reasoning that students use is need-based reasoning (e.g., ducks *needed* to swim faster, so nature allowed them to develop webbed feet), in which the need for the property (due to its function) is the mechanism of change (Bishop & Anderson, 1990; Clough & Wood-Robinson, 1985; Deadman & Kelly, 1978; Greene, 1990; Jensen & Finley, 1995; Jiménez-Aleixandre, 1992; Kampourakis & Zogza, 2008, 2009; Settlage, 1994). These findings lend support to Kelemen's (2012) view that there is a powerful human bias to view properties of organisms as existing for a purpose (e.g., horses have tails in order to swat away flies). A tendency to focus on function or purpose is found in all age groups, but may be particularly strong in children (Kelemen, 1999). Importantly, teleological reasoning is inconsistent with evolutionary reasoning, whereby the mechanism of change stems from *random* variation within a species and the selection over time of those properties that promote survival. That is, the mechanism of change is not the purpose or necessity of the property per se, nor is it under organisms' direct control, as these explanations imply.

1.1. Overview of current studies

Prior research demonstrating the prevalence of teleological reasoning about evolution has focused primarily on the emergence and persistence of properties across an entire species, and often across several generations. A significant unanswered question, addressed in the current series of studies, is whether this misconception extends to thinking about individual organisms. For example, students may think that an animal will acquire a property if it is placed into an environment where it needs the property to survive. This is an important question because it provides insight into lay concepts of biological understanding more broadly. On the one hand, if undergraduates do not exhibit teleological reasoning at the individual-organism level, it would suggest that their misconceptions pertain strictly to larger scale aspects of evolution, such as the

process of individual variation within an entire species (e.g., Shtulman & Schulz, 2008). On the other hand, if undergraduates do exhibit teleological reasoning at the individual-organism level, it would suggest that their difficulty in understanding evolutionary processes includes misconceptions about the inheritance and acquisition of properties during a single organism's lifetime. This would constitute a considerably greater misconception of evolutionary processes. In particular, teleological reasoning at the level of the species may simply be an intuitive or short-hand way of talking about true evolutionary change. That is, students may understand the process of evolutionary change, but may have particular difficulty articulating the steps involved, causing them to resort to teleological language (Deadman & Kelly, 1978). In contrast, teleological reasoning at the level of the individual is more grossly incompatible with evolutionary thinking because it implies a deep misconception about the processes underlying property inheritance and acquisition.

We used an adoption paradigm in the current research, borrowed from studies of cognitive development (Astuti, Solomon, & Carey, 2004; Johnson & Solomon, 1997; Solomon et al., 1996; Springer, 1996). In this paradigm, the participant is told a hypothetical scenario about a baby animal (human or non-human) that is separated from its biological parent(s) after birth and then raised by another (biologically unrelated) parent(s). The participant is then asked whether the young animal will be like its birth parent or its rearing parent on a property dimension on which they differ. Hence, the participant must decide whether the property in question stems more from "nature" (i.e., innate factors) or "nurture" (i.e., environmental factors). This paradigm is thus very useful for uncovering which sorts of properties are viewed as more heritable (or more malleable) within a single generation. This direct pitting of biological endowment against rearing environment influences has not been examined in the prior science education work.

We conducted seven studies that used the adoption paradigm to compare participants' inheritance reasoning about properties with functional implications ("function-predictive") to their reasoning about properties with no such implications ("non-predictive"). That is, the birth and rearing parents differed on a given physical property dimension, and these properties either had distinct functions, or had no functions. Participants were asked to choose whether they thought the offspring would be like its birth parent or rearing parent on the given physical property dimension, and (with the exception of the child participants in Study 7) to explain the rationale for their choice.

This design had the advantage of allowing us to test for two competing hypotheses regarding how function might affect inheritance judgments. The first, which we refer to as the *purpose-based stance*, is most consistent with the teleological reasoning seen in tasks involving reasoning about the evolution of traits within a species (i.e., that properties emerge within a species as needed). Specifically, the purpose-based stance posits that functional properties will be viewed as less heritable and more modifiable than properties without functions. Participants may assume that features with useful functions—particularly those with potential survival implications—may be so important that animals will somehow acquire these properties even when there is no plausible mechanism for doing so. That is, the purpose of features and an animal's survival needs may be thought to

dictate the features it acquires. For example, in an adoption scenario, if the birth parent and the rearing parent have contrasting properties with contrasting functions (e.g., the birth parent's short tail has a particular function, and the rearing parent's short long tail a different function), it may be assumed that the rearing parent's feature has functional advantages in the rearing environment, which will therefore lead the young animal to acquire it. People may reason, in effect, "Property Y will allow Animal X to survive. Therefore, it will acquire property Y." Thus, to the extent that they hold a purpose-based stance, participants in the current research were expected to judge that offspring would share functional properties with its rearing parent, and in their explanations to appeal to the function, advantage, or necessity of the property.

The second possibility, which we dub as the *inheritance-of-essentials stance*, holds that functional properties will be more heritable and less modifiable. This framework rests on the premise that properties that are viewed as more important and closer to the "core" of one's concept of a particular kind are more likely to be treated as inherent to that kind and thus passed down from parent to child (Gelman, 2003). The basic idea here is that there is a direct, positive correspondence between how central a feature is and how likely it is to be passed along. This possibility is supported by prior research showing that features with clear functional implications are viewed as more central to categories than non-functional features (DiYanni & Kelemen, 2005) and are more likely to be inherited (Springer & Keil, 1989) and remain stable over time within a category (Lombrozo & Rehder, 2011). A key question that has not been explored, however, is whether people's bias towards viewing functional properties as central and inherited is influenced in any way by the utility of the property's function within an animal's environment. To the extent that people hold an inheritance-of-essentials stance, their bias should persist even for properties that may not be particularly useful in the rearing environment. Thus, they should judge that offspring will share functional properties with the birth parent and, when asked to explain their reasoning, they should appeal to the inborn nature of the property, to the kinship linkage between the birth mother and the offspring, or to genetic mechanisms. Note that these predictions contrast with those of the teleological view that properties can be acquired via purpose or necessity.

We also examined heritability judgments about properties that do not have functions per se, but are associated with the habitat in which the animal lives ("habitat-predictive"; e.g., what the animals eat, where they live). In this condition, the birth and rearing parents differed on a given physical property dimension that was linked to distinct aspects of their habitats (e.g., the birth parent has a short tail, and animals with short tails live in the jungle; the rearing parent has a long tail, and animals with long tails live in the forest). One possibility is that habitat information will be viewed as irrelevant to judgments of inheritance; as they invoke neither function nor core features, they could be viewed as irrelevant to both the purpose-based and inheritance-of-essentials stances. If so, then habitat-predictive vignettes should yield results identical to those of the non-predictive vignettes. However, it is also possible that habitat per se will be viewed as significant. Specifically, participants may assume that properties that are linked to one's habitat serve some functional purpose and are thus more advantageous. If so, then, like the

function-predictive properties, participants' responses to habitat-predictive properties should reveal different patterns depending on whether a purpose-based stance or an inheritance-of-essentials stance is invoked. If participants rely on a purpose-based stance, then the habitat-predictive properties should imply purpose and thus, like the function-predictive properties, should be viewed as more modifiable than non-predictive properties. In contrast, if participants rely on an inheritance-of-essentials stance, then the habitat-predictive properties should imply an important core feature (function) and thus, like the function-predictive properties, should be viewed as less modifiable than the non-predictive properties. Thus, comparing the habitat-predictive properties to the function-predictive properties allowed us to examine whether participants interpret habitat information as implying purpose.

Across the studies reported below, we varied the types of animals, physical properties, and property implications tested, as well as the age and level of expertise of the participants. Studies 1–5 focused on undergraduates. In Study 1, we examined undergraduates' inheritance reasoning for external physical properties, including those with or without functional implications, and those with or without associations with habitat. Study 2 provided a stronger test of purpose-based reasoning by examining internal physical properties (with or without functional or habitat implications), which are less modifiable via direct means. Study 3 sought to more precisely examine the contexts that promote purpose-based reasoning by asking whether it is specific to properties with functional or habitat implications or, alternatively, applies to any causal or correlational property. Study 4 asked whether undergraduates believe that a trait acquired due to its function or associations with habitat can be passed onto the next generation of offspring (i.e., use Lamarckian reasoning). Study 5 asked whether the effects obtained with undergraduates in Study 1 (which asked participants about novel animal categories) would also extend to real-world categories. Study 6 tested a comparison sample of biology experts (using the same materials and procedure from Study 1) to assess the effect of expertise on inheritance reasoning. Lastly, Study 7 tested 4- and 5-year olds to assess the effect of age on inheritance reasoning. Taken together, these studies provide a comprehensive picture of the extent of purpose-based reasoning in inheritance judgments and the factors that contribute to it.

In Studies 1–3 and 5, we also varied whether the offspring's birth and rearing parent were the same kind of animal (*within-category* condition) or different kinds of animals (*between-category*). Prior research on inheritance reasoning has not systematically manipulated this variable; individual studies have focused on either within- or between-category comparisons. On the one hand, it is possible that undergraduates will view properties as more modifiable in the case of within-category adoption scenarios as it might be considered more probable that category members can possess either parent's property value and readily change between them as needed. On the other hand, some prior science education research has shown that students are more naïve in their reasoning about between-species evolutionary change (e.g., how a species of flightless birds may have evolved from flying bird species; Nehm & Ha, 2011). Thus, we might similarly find greater errors in between-category inheritance reasoning.

2. Study 1

2.1. Method

2.1.1. Participants

Participants were 98 college students (18–22 years; 60 males and 38 females) enrolled in an introductory psychology course at a large university in the Midwestern USA. They completed the study for course credit. They self-identified their racial/ethnic background as follows: 71 White, 14 Asian, 7 African American/Black, 5 Hispanic or Latino, and 1 unreported.

2.1.2. Materials and procedure

Participants were given a test booklet containing 16 vignettes, each presented on a separate page (see Appendix for samples). The vignettes were written at a level that would be comprehensible to preschoolers (for Study 7). Participants were instructed that they would be reading stories about animals that live on a planet that is far away. This was done to provide context for these wholly unfamiliar animals. Each vignette described an adoption scenario in which a baby animal was born to one animal (hereafter referred as the *birth parent*) but was taken care of by and grew up with another animal (the *rearing parent*), and was never again seen by the birth parent. The young animal was now 6 years old (so that both maturation and environment would have sufficient time to exert effects). A line drawing of each parent animal was displayed at the top of the page; both were novel, made-up animals (Fig. 1). Novel animals were used in order to reduce the possibility that participants would rely on any prior category knowledge. The baby was not depicted visually, as we did not wish participants to make inferences based on visual cues. The parents were referred to with novel labels and were never referred to using terms relating to parentage or adoption, so as not to provide any biasing language. Half the participants were randomly assigned to a *between-category* condition and half were assigned to a *within-category* condition. In the between-category condition, each vignette
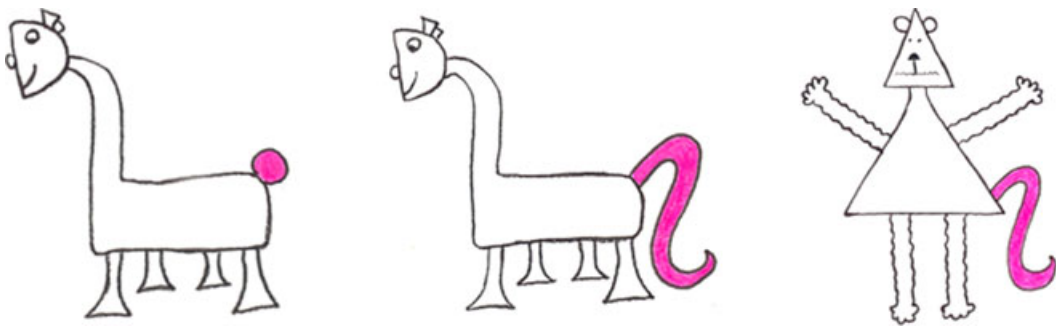

Fig. 1. Sample drawings depicting the parent animals from the within-category (left and middle) and the between-category (left and right) versions of one vignette (in which the contrasting property was short vs. long tail).

stated that the birth and rearing parents were different kinds of animals and they were labeled with different novel count nouns (e.g., a lep, a vit). They also differed substantially in appearance (e.g., different body shape and appendages), including on the physical property dimension being contrasted. In the within-category condition, each vignette stated that the parents were the same kind of animal and they were labeled with different proper names (e.g., Lep, Vit). They were also similar in appearance with the exception of the physical property being contrasted (e.g., they had identical body shapes but the birth parent had a short tail and the rearing parent had a long tail).

Following the adoption scenario in each vignette, it was explicitly pointed out that the birth and rearing parents had contrasting values on a particular external physical property dimension (e.g., short tail vs. long tail). Any additional information given about these properties varied within-subjects across three vignette versions—function-predictive, habitat-predictive, and non-predictive (Table 1).[1] In the *function-predictive* vignettes, the birth and rearing parents' physical properties were described as having distinct functions. The functions were similar to those of external properties in real-world animals and caused effects that one might assume would influence the baby animal's ability to survive in the rearing environment. For example, in the vignette pictured in Fig. 1, the birth parent had a short tail that she "wiggles to show that she is excited," and the rearing parent had a long tail that she "waves to knock bugs off of her back." In the *habitat-predictive* vignettes, the birth and rearing parents' physical properties were associated with distinct aspects of their habitats (what the animal eats or what habitat it lives in). For example, participants read that "…on this planet, animals with short tails live in the jungle…on this planet, animals with long tails live in the forest." In the *non-predictive* vignettes, the parents' contrasting physical properties were pointed out, but no further information about them was given.

In each vignette, after the adoption scenario and the property information were presented, participants were asked two questions. First, they were asked to choose whether they thought the baby (now 6 years old) had the same external physical property as the birth parent or the rearing parent (e.g., Do you think that the baby has long fur like the lep or short fur like the vit?). Second, they were asked to give an explanation for their response to the first question.[2]

The vignettes were presented in two blocks of eight. In the function block, there were four function-predictive vignettes and four non-predictive vignettes. In the habitat block, there were four habitat-predictive vignettes and four non-predictive vignettes. Assignment to block order was random, with each order occurring equally across participants.

There were eight pairs of birth- and rearing-parent drawings in the between-category condition, and eight pairs in the within-category condition. (One animal from each of the between-category pairs was duplicated to create each within-category pair.) Each pair corresponded to a different set of contrasting physical properties. Each pair was presented in both the function and habitat blocks, but different novel labels were used to refer to them in each block. Participants were instructed that the same pictures would accompany different stories throughout their test booklet and that they should not use information read in an earlier story to answer questions about a later story. The property pairs were presented in different orders across the function and habitat blocks, but the within-block

Table 1
Predictive information provided for each external property pair (Study 1)

Property Pair	Function-Predictive	Habitat-Predictive
Bumpy skin versus Smooth skin	Bumpy skin helps her to swim fast when she is in water Smooth skin helps protect her body when she climbs rocks	Animals with bumpy skin live in the desert Animals with smooth skin live in the mountains
Short tail versus Long tail	Wiggles her short tail to show that she is excited Waves her long tail to knock bugs off of her back	Animals with short tails live in the jungle Animals with long tails live in the forest
Spotted versus Striped	Spots are good for attracting butterflies that clean her skin Stripes are good for scaring away dangerous animals	Animals with spots eat mice Animals with stripes eat worms
Curved toes versus Sharp claws	Uses her curved toes to dig holes Uses her sharp claws to catch fish	Animals with curved toes eat berries Animals with sharp claws eat grass
Long fur versus Short fur	Long fur helps her to stay warm when it is cold outside Short fur helps her to stay cool when it is hot outside	Animals with long fur live in the jungle Animals with short fur live in the forest
Green skin versus Blue skin	Green skin helps her stay hidden when she is in the forest Blue skin helps her stay hidden when she is in the water	Animals with green skin eat mice Animals with blue skin eat worms
Straight mane versus Curly mane	Straight mane helps her to keep her face dry. Because when it rains, water drips onto her mane and not her face Curly mane helps her to get food. Because bugs get caught in her curly mane, and she eats them	Animals with straight manes live in the mountains Animals with curly manes live in the desert
Pointy ears versus Floppy ears	Pointy ears help her to hear sounds that are far away Floppy ears help her to keep bugs out of her ears	Animals with pointy ears eat berries Animals with floppy ears eat grass

Note. In the habitat-predictive condition, all property descriptions began with the phrase, "On this planet, animals with…"

order was always the same. The assignment of each property pair to predictive status differed across two versions: in version A, four predetermined property pairs were predictive in the function block and non-predictive in the habitat block, and the other four pairs were non-predictive in the function block and predictive in the habitat block. This was reversed for version B. In both versions, the predictive and non-predictive vignettes appeared intermittently within each block. Half of the participants completed version A and half completed version B. All variables (between- or within-category, block order, and version A or B) were counterbalanced across participants.

2.1.3. Explanation coding

Participants' explanations for their choices were coded into four categories: stable, teleological, modifiable, and other. Examples of each type are shown in Table 2. Explanations were coded as *stable* when participants appealed to biological or genetic mechanisms; stated that the property could not be influenced by environmental factors, was permanent, or unchangeable (at least within a single generation); and/or appealed to

Table 2
Examples of stable, teleological, and modifiable explanations

Stable	• The baby would take after its biological mother
	• Mober had the baby so the baby would look like Mober even if it grew up with Dassy
	• This would be a genetic trait, meaning it comes from the birth mother, not the one that the baby lives with
	• Physical appearance is based on genetics not environment
	• The physical appearance due to genetic makeup of the animal cannot change just by changing the kind of food the baby will eat
	• It is Taw's baby and ears usually do not change
	• The baby is a noop and noops have curved toes
Teleological	• Because the length of fur is being used, the baby may adapt to his/her new environment
	• The baby lives with the warb and therefore eats worms and needs to have blue skin to eat worms
	• Since the baby lives with min it needs sharp claws to catch fish and therefore develops sharp claws
	• The dax will need the spots to help attract butterflies that clean her skin
	• Since fur helps your body temperature, the child would adapt to short fur with its caretaker
	• Must survive with surrogate mother and environment
	• The baby has to adapt to its surroundings
Modifiable	• Vit lives in forest and took care of baby, therefore the baby has short fur
	• Baby lives and eats with the warb; exposed to same environment
	• The baby had short fur because it changed according to its habitat and surroundings
	• The child's skin may have changed to blue since it was raised to eat worms probably
	• Toe shape could result from usage of toes. So after living with the min, maybe the noop got claws
	• Depending on the environment, animals may develop specific traits
	• Environmental forces will influence the baby to have floppy ears
	• Because of nurture
	• The baby might copy her surrogate mother's style
	• Since the ret was raising the baby, it let the tail grow out so the baby would look more like its own

Note. Some explanations have been edited or abridged for grammar or brevity.

the baby's or biological parent's category membership as a reason for the baby's outcome.

Explanations were coded as *teleological* if the participant implied that the baby's value on the property dimension was influenced by the property's function, advantage, or necessity. This included when participants stated that the baby needed the selected property to survive; stated that the baby had to or would adapt to the rearing environment; or referred to the purpose, usefulness, or advantage of having the selected property. Explanations were also coded as teleological if the participant implied that, even if the baby had the same property as the biological parent, it could acquire the rearing parent's property if it needed to do so to survive. We initially included a separate category of teleological explanations that also referred to intentional modification by the young animal or its rearing parent (e.g., "The baby might have somehow shaved its fur to adapt to the environment"). However, these explanations occurred infrequently (1.4% of all explanations; 16% of all teleological explanations) and showed the same overall patterns as non-intentional teleological explanations described below. We therefore collapsed intentional and non-intentional teleological explanations into a single teleological category.

Explanations were coded as *modifiable* when participants stated that the baby's value on the property dimension could change in its lifetime, but did not invoke a teleological factor. This mostly included explanations appealing to external influences, such as stating that the property depends on or is influenced by aspects of the environment or habitat, or is a property that the baby or parent could modify intentionally (but not out of need or functionality). Occasionally, participants stated that the property was temporary or transient in nature, and these explanations were also coded as modifiable.

Lastly, explanations were coded as *other* if they did not clearly fall into one of the above categories (e.g., because the participant expressed uncertainty ["Not sure"] or did not provide any specific mechanism information ["Should be like Vit"]). Because we had no predictions for this class of explanations, we did not include them in the analyses.

Explanations could be coded as both stable and modifiable or as both stable and teleological if the participant invoked multiple contributing factors (e.g., "Has same genes as mother [stable] but also depends on the diet of the animal [modifiable]"). A single explanation could not be coded as both modifiable and teleological because these categories were mutually exclusive by definition.

The explanations for Studies 1–4 were coded by two coders. The first author coded all of the explanations and a second coder coded those of 20% of participants. Inter-rater reliability was high—the two coders agreed 93% of the time, on average across the studies (average $\kappa = .79$). Disagreements were resolved through discussion.

2.2. Results

2.2.1. Birth choices

Participants were given a 1 for every vignette on which they selected that the baby would have the same external property value as its birth parent. Three proportion scores were calculated for each participant corresponding to their rate of birth-parent choices in

each vignette version (function-predictive, habitat-predictive, non-predictive). Overall, participants exhibited a strong birth-parent bias; one sample-tests showed that their rate of birth-parent choices exceeded chance (0.5) in all vignette variants (function-predictive: $M = 0.83$, $t(97) = 12.32$, $p < .001$; habitat-predictive: $M = 0.69$, $t(97) = 5.18$, $p < .001$; non-predictive: $M = 0.94$, $t(97) = 32.86$, $p < .001$). To examine whether the strength of this bias was influenced by the predictive status of the properties, we conducted a mixed ANOVA on the proportion scores with vignette version (function-predictive, habitat-predictive, non-predictive) as a within-subject factor and block order (function block first, habitat block first) as a between-subject factor. There were no significant effects of between-versus within-category on participants' responses in any of the studies that manipulated this factor (Studies 1–3 and 5); this factor is thus eliminated from the reported analyses. The analysis revealed a main effect of vignette version, $F(2, 192) = 38.1$, $p < .001$, $\eta^2 = .27$. Participants made more birth-parent choices on the non-predictive vignettes, compared to either the function- or habitat-predictive vignettes, and made the fewest birth-parent choices in the habitat-predictive condition (all ps $< .001$). (All descriptions of the specific directions of main effects and interactions were obtained from planned comparisons involving t tests with LSD corrections for main effects and Bonferroni corrections for interactions.) Thus, participants' birth bias was lessened when the properties in question had functions, and even more so when they were associated with habitat.

This analysis also revealed a significant vignette × block order interaction, $F(2, 192) = 5.26$, $p < .01$, $\eta^2 = .04$. When the function block was completed first, the rate of birth-parent choices on the function-predictive vignettes was only marginally lower than the non-predictive vignettes ($p = .06$), and when the habitat block was completed first, there was no difference between the rate of birth-parent choices on the habitat-predictive and function-predictive vignettes (though both were still lower than the non-predictive vignettes).

2.2.2. Explanations

We first examined whether participants' choices were consistent with their explanations. For each vignette version, we calculated the proportion of birth-parent choices and the proportion of rearing-parent choices for which participants invoked each of the three explanation types (stable, modifiable, teleological). We conducted a repeated measures ANOVA on birth-parent choice explanations with vignette version (function-predictive, habitat-predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors (Table 3). Participants who did not make at least one birth-parent choice in all three versions ($n = 13$) were excluded from the analyses. There was a significant main effect of explanation type, $F(2, 168) = 1946.70$, $p < .001$, $\eta^2 = .96$. Stable explanations for birth-parent choices ($M = 94.7\%$ of responses) were more frequent than either modifiable ($M = 4.7\%$) or teleological ($M = 4.2\%$) explanations (ps $< .001$). There was also a significant vignette × explanation type interaction, $F(4, 336) = 5.72$, $p < .001$, $\eta^2 = .06$. Modifiable explanations were more frequent on the habitat-predictive vignettes than on the function-predictive ($p < .05$) and non-predictive vignettes ($p < .01$). In contrast, teleological explanations were more frequent on the function-predictive

Table 3
Mean frequency of explanation types by vignette version and choice (Study 1)

	Explanation Type		
	Stable	Modifiable	Teleological
Function-Predictive			
Birth parent	0.95	0.01	0.08
Rearing parent	0.08	0.38	0.55
Habitat-predictive			
Birth parent	0.92	0.10	0.04
Rearing parent	0.05	0.59	0.34
Non-predictive			
Birth parent	0.97	0.03	0.01
Rearing parent	0.16	0.56	0.29

vignettes than on the non-predictive vignettes ($p < .01$), and also occurred with greater frequency than modifiable explanations on the function-predictive vignettes ($p < .05$).

Because rearing-parent choices were less frequent overall, there were few participants that had rearing-parent explanation data for all vignette versions. We therefore analyzed the frequency of explanation types separately for each version, and included in each analysis only those participants who had explanation data for that version (function-predictive: $n = 36$; habitat-predictive: $n = 52$; non-predictive: $n = 29$). We conducted three repeated measures ANOVAS with explanation type (stable, modifiable, teleological) as a within-subject factor in each. These analyses revealed main effects of explanation type in all versions (function-predictive: $F(2, 70) = 8.72$, $p < .001$, $\eta^2 = .20$; habitat-predictive: $F(2, 102) = 20.80$, $p < .001$, $\eta^2 = .29$; non-predictive: $F(2, 56) = 5.52$, $p < .01$, $\eta^2 = .16$). In all conditions, modifiable explanations for rearing-parent choices were provided more frequently than were stable explanations (all $ps \leq .001$). On the habitat-predictive vignettes, modifiable explanations were also more frequent than teleological explanations ($p < .05$). Lastly, on both the function-predictive and habitat-predictive vignettes, teleological explanations were more frequent than stable explanations ($ps < .001$).

2.2.3. Individual differences

We also wanted to examine whether there were patterns of individual differences across participants' explanations and choices. We were particularly interested in comparing participants who exhibited different patterns of rearing-parent choices across the vignette versions. We therefore categorized participants into one of the following groups: *no-rearing*, if they made only birth-parent choices and no rearing-parent choices ($n = 39$); *habitat-predictive-only*, if they made at least one rearing-parent choice on the habitat-predictive vignettes but none on the function-predictive vignettes ($n = 21$); *function-predictive-only*, if they made at least one rearing-parent choice on the function-predictive vignettes but none on the habitat-predictive vignettes ($n = 6$); and *function-and-habitat*, if they made rearing-parent choices on both predictive versions ($n = 31$). (One participant only made rearing-parent choices on the non-predictive vignettes and

was excluded from these analyses.) We then examined whether the rate of stable, modifiable, and teleological explanations differed across these groups. For these analyses, we summed the total number of explanations of each type for each participant (collapsed across vignette and choice).We conducted three separate one-way ANOVAS to examine the effect of choice pattern on each explanation type. There was a main effect of choice pattern on all explanation types (stable: $F(3, 93) = 71.53$, $p < .001$, $\eta^2 = .70$; modifiable: $F(3, 93) = 22.72$, $p < .001$, $\eta^2 = .42$; teleological: $F(3, 93) = 20.4$, $p < .001$, $\eta^2 = .40$). Participants with the function-and-habitat choice pattern provided the fewest stable explanations, the most teleological explanations, and more modifiable explanations than all others except the habitat-predictive-only group. Participants with the no-rearing pattern provided the most stable explanations and provided fewer modifiable explanations than the habitat-predictive-only group. There were no differences in explanation rates between the habitat-predictive-only and function-predictive-only groups. Thus, overall the greatest rate of non-scientific explanations was seen in participants who made rearing-parent choices when properties were predictive, regardless of whether they predicted function or habitat.

2.3. Discussion

In Study 1, undergraduates exhibited a relatively strong birth-parent bias when judging the heritability of external physical properties. However, for many participants, this bias was weakened when the properties in question caused distinct functions that would presumably influence the offspring's ability to survive in its rearing environment. The birth bias was reduced even further with properties that did not have specific functions but were associated with distinct aspects of the birth and rearing habitats.

Participants' explanations for their choices also varied based on the properties' implications. Overall, their explanations were consistent with their choices—they referred to biological, genetic, or category-based mechanisms to explain birth-parent choices and, in contrast, referred to the functional or modifiable nature of the property to explain rearing-parent choices. Teleological explanations were particularly likely when the properties in question had functional implications. Teleological explanations were also provided when the properties predicted habitat conditions, but did not have functions, but participants were most likely in this case to appeal to environmental influences on the property or to its modifiable nature more generally. These effects were observed even when participants judged that the baby would be like its birth parent on the given property dimension (although stable explanations were most frequent overall for birth-parent choices). Thus, even though participants exhibited a birth bias in these cases, they still were inclined to appeal to the functional or modifiable nature of the properties as contributing to the young animal's outcome in some way.

Overall, these results are consistent with a purpose-based stance of functional properties—that is, that properties with functional consequences can be acquired by animals because they serve an important purpose. Participants were more likely to report that a baby animal could acquire the same property as its rearing parent when the property had functional consequences that could potentially influence its ability to survive in its rearing

environment. Moreover, participants frequently invoked teleological factors when explaining their reasoning.

The findings for properties associated with the habitat had both key similarities and key distinctions from functional properties. First, the results for the habitat-predictive condition demonstrate that, in addition to functional implications, undergraduates also consider it more likely that an animal will acquire a property when it is associated with its rearing habitat. This is consistent with a purpose-based stance of inheritance and demonstrates that both functional and habitat implications weigh into undergraduates' inheritance judgments.

Another key similarity is that both properties with functional implications and properties with habitat implications promoted teleological reasoning. Thus, even in the latter case, when properties only have implied functions, undergraduates are inclined to engage in teleological reasoning. However, a key difference between the function- and habitat-predictive contexts is that teleological explanations were the dominant rationale for the former, whereas for the latter, participants were most likely to appeal to external influences and the modifiable nature of the property. These findings suggest that teleological reasoning, which violates modern evolutionary principles, is most likely when considering the inheritance of features with functional implications. In contrast, with features that are associated with habitat, undergraduates' reasoning errors may be less severe. On the one hand, modifiable explanations were unsupported in the current paradigm given that there was no information provided about causal links between the habitat properties and the external properties. On the other hand, this mode of reasoning is not necessarily a violation of Darwinian evolutionary principles as there are cases in which organisms are directly influenced by or acclimate to environmental conditions (e.g., sheep grow thicker wool when placed in colder climates; humans' oxygen capacity gradually adjusts to high altitude climates). Thus, the current findings demonstrate that the most severe violations in inheritance reasoning (i.e., teleological reasoning) occur with the specific case of functional properties.

We also found interesting individual difference patterns in naïve and scientific inheritance reasoning. Specifically, there was a subset of participants who made rearing-parent choices when properties were predictive, regardless of whether they predicted function or habitat, and it was these participants who provided the highest rate of non-scientific explanations. There was another subset that provided more scientific explanations than others. Thus, there are variations among undergraduates in their understanding of inheritance and evolution, ranging from those with extreme misconceptions to those with more accurate ideas.

3. Study 2

The findings of Study 1 demonstrate that some undergraduates believe that physical properties can be acquired if they serve a purpose for an animal, or if they are linked to an animal's habitat. One possible explanation for these findings is that participants

believed that intentional, agentive mechanisms were involved, rather than a biological or evolutionary process. Prior research has shown that a common misconception in evolutionary reasoning involves anthropomorphizing, or ascribing human-like intentional actions to animals (e.g., in Study 1, the animals might be able to curl their manes via some sort of external process) (Kampourakis & Zogza, 2008). Moreover, both students and educators often use language that implies that nature and the process of natural selection are agentive (e.g., referring to nature as a "driving force" that "selects for" or "favors" advantageous properties; Gregory, 2009). Likewise, participants in Study 1 may have believed that some sort of intentional, agentive mechanism could cause property changes, even when they did not explicitly mention this in their explanations.

Study 2 examines this possibility by examining whether purpose-based reasoning persists when the properties in question are less likely to be modified intentionally—specifically, when they are internal. We used a similar procedure to Study 1 in which the predictive nature of properties was manipulated, but the properties were internal. Although internal properties can change over the course of an organism's lifetime, such as via acclimatization, they are more difficult to modify intentionally than are external properties. This is particularly the case for non-human animals. Moreover, we tested properties in Study 2 that even human agents would have difficulty modifying intentionally (without medical technology), such as the color or shape of internal organs, or the presence of certain substances in the blood. Thus, if undergraduates view purpose-based change as strictly the result of intentional modifications, then the effects of functional implications and associations with habitat that were seen in Study 1 should lessen or disappear altogether in Study 2 when inquiring about internal properties. In contrast, if undergraduates believe that properties can be acquired based on their purposeful nature, even when a mechanism of intentional modification is less plausible, then we should replicate the results in Study 2.

3.1. Method

3.1.1. Participants

Participants were 69 college students (18–22 years; 31 males and 38 females) enrolled in an introductory psychology course at a large university in the Midwestern USA. They completed the study for course credit. They self-identified their racial/ethnic background as follows: 54 White, 9 Asian, 5 African American/Black, and 1 Hispanic or Latino. One additional participant was tested but opted not to complete the entire study.

3.1.2. Materials and procedure

Participants were given a booklet containing 16 adoption vignettes. The instructions and general format of the vignettes were identical to Study 1. However, in this study, the birth and rearing parents were described as having contrasting property values on an *internal* property dimension. The same external property differences tested in Study 1 were visible, but were not explicitly mentioned.

As in Study 1, there were three vignette versions: function-predictive, habitat-predictive, and non-predictive. The vignettes were presented in two blocks, with four function-predictive and four non-predictive vignettes in the function block, and four habitat-predictive and four non-predictive vignettes in the habitat block. Examples of the internal property pairs and their function- and habitat-predictive descriptions are provided in Table 4. In the function-predictive condition, the parents' contrasting internal properties were made-up substances that the animals had in their blood, bones, brain, or heart. In each vignette, the birth and rearing parents were described as having different substances (e.g., "zeride" and "dorvus") in the same location (e.g., "in its blood"). The functions of the substances were the same functions described in the function-predictive vignettes in Study 1. In the habitat-predictive condition, the contrasting properties were characteristics of internal parts or organs (e.g., yellow vs. green brain). As in Study 1, these properties were correlated with certain aspects of the parents' habitats (what the animal eats or where it lives), but were not explicitly causally related to them.[3]

The non-predictive vignettes were similar to Study 1; however, in this study, the non-predictive status of the properties was made more explicit so as to reduce the likelihood that participants would make any assumptions about possible implications of the internal properties. In the non-predictive vignettes in the function block, participants were told that the internal properties had no functional implications (e.g., "…the zeride does not do anything. It just stays there in her blood."). In the non-predictive vignettes in the habitat block, the birth and rearing parents' internal properties were linked to identical habitats (e.g., when describing both parents, participants were told that, "on this planet, animals with flat/round bones live in the jungle"). Hence, they were not uniquely predictive of any aspect of the rearing environment.

Table 4
Examples of the predictive descriptions of the internal properties pairs (Study 2)

Function-Predictive Condition	Habitat-Predictive Condition
Ronocyte in her heart makes her wiggle her tail when she is excited	Animals with flat bones live in the jungle
Kestin in her heart makes her wave her tail to knock bugs off her back	Animals with round bones live in the forest
Zeride in her blood makes her good at digging holes	Animals with a kidney in their body eat bugs
Dorvus in her blood makes her good at catching fish	Animals with an appendix in their body eat fruit
Farium in her bones helps her to attract butterflies that clean her skin	Animals with a green brain eat mice
Mastin in her bones helps her to scare away dangerous animals	Animals with a yellow brain eat worms
Lobana in her brain helps her to stay hidden when she is in the forest	Animals with a flat heart eat fish
Dermide in her brain helps her to stay hidden when she is in the water	Animals with a round heart eat nuts

Notes. The internal property contrast was described before the predictive information (e.g., "The clee has something called ronocyte in her heart. The murb has something called kestin in her heart).

At the end of each vignette, participants were asked the same questions as Study 1—they chose whether the baby (at age 6) would have the same (internal) property as the birth or rearing parent, and provided an explanation for their choice. Half of participants completed a between-category version and half completed a within-category version of the vignettes. The vignette ordering and counterbalancing procedures were identical to Study 1.

3.2. Results

3.2.1. Birth choices

Overall, participants showed a high birth bias, with the number of birth-parent choices exceeding chance (0.5) in all vignette variants (function-predictive: $M = 0.90$, $t(68) = 13.32$, $p < .001$; habitat-predictive, $M = 0.88$, $t(68) = 11.76$, $p < .001$; non-predictive: $M = 0.97$, $t(68) = 42.09$, $p < .001$). To see if this bias varied in strength depending on the properties' functional implications, we conducted a repeated measures ANOVA on the number of birth-parent choices with vignette version (function-predictive, habitat-predictive, non-predictive) as a within-subject factor and block order (function block first, habitat block first) as a between-subject factor. There was a main effect of vignette, $F(2, 134) = 4.28$, $p < .05$, $\eta^2 = .06$; participants made more birth-parent choices on the non-predictive vignettes compared to both the function-predictive ($p < .05$) and habitat-predictive ($p < .01$) vignettes. There was also a marginally significant vignette × block order interaction, $F(2, 134) = 2.54$, $p = .08$, $\eta^2 = .03$. The rate of birth-parent choices on the function-predictive vignettes was higher when the function block was completed first than when the habitat block was completed first ($p < .05$).

We next compared the frequency of birth-parent choices across Studies 1 and 2. In Study 1, 40% of participants ($n = 39$) made birth-parent choices exclusively, compared to 68% ($n = 47$) in Study 2. We conducted independent samples t tests to compare the rate of birth-parent choices across studies in the three vignette versions. There was a marginally significant difference in the function-predictive condition, $t(165) = 1.66$, $p = .10$, and a significant difference in the habitat-predictive condition $t(165) = 3.81$, $p < .001$, with participants making more birth parent choices in Study 2.

3.2.2. Explanations

We examined the explanations for birth-parent choices using a repeated measures ANOVA with vignette version (function-predictive, habitat-predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors (Table 5). Participants who did not make at least one birth-parent choice in all three vignette conditions ($n = 6$) were excluded. There was a main effect of explanation type, $F(2, 124) = 2907.89$, $p < .001$, $\eta^2 = .98$. Stable explanations ($M = 0.98$) were provided more frequently than either modifiable ($M = 0.03$) or teleological explanations ($M = 0.04$) (all ps $< .001$). There was also a significant vignette × explanation type interaction, $F(4, 248) = 3.5$, $p < .01$, $\eta^2 = .05$. Modifiable explanations were provided more frequently on the habitat-predictive vignettes compared to the non-predictive vignettes ($p < .05$), and

Table 5
Mean frequency of explanation types by vignette version and choice (Study 2)

	Explanation Type		
	Stable	Modifiable	Teleological
Function-predictive			
Birth parent	0.97	0.03	0.05
Rearing parent	0	0.36	0.56
Habitat-predictive			
Birth parent	0.97	0.06	0.01
Rearing parent	0.25	0.56	0.27
Non-predictive			
Birth parent	0.99	0.01	0.05
Rearing parent	0.16	0.64	0.05

teleological explanations were provided more on the function-predictive vignettes than the habitat-predictive vignettes ($p < .05$).

For rearing parent choice explanations, we examined the data for each vignette variant separately, including only those participants who made at least one rearing parent choice in each condition (function-predictive: $n = 12$; habitat-predictive: $n = 14$; non-predictive: $n = 11$). There were main effects of explanation type for both the function-predictive, $F(2, 22) = 4.79$, $p < .05$, $\eta^2 = .30$, and non-predictive vignettes, $F(2, 20) = 6.73$, $p < .01$, $\eta^2 = .40$. On the function-predictive vignettes, both modifiable and teleological explanations were provided more than stable explanations (both ps $< .05$). On the non-predictive vignettes, modifiable explanations were provided more than stable ($p = .06$) and teleological explanations ($p < .01$). There was no main effect of explanation type for the habitat-predictive vignettes, but paired t tests showed that modifiable explanations occurred marginally more than stable explanations ($p = .11$).

3.2.3. Individual differences

As in Study 1, we also examined individual differences in participants' explanation and choice patterns by classifying participants as no rearing ($n = 47$), habitat-predictive-only ($n = 8$), function-predictive-only ($n = 6$), and function-and-habitat ($n = 6$), and compared explanation rates across these groups (in three separate one-way ANOVAS). (Two participants who only made rearing-parent choices on the non-predictive vignettes were excluded from these analyses.) There was a main effect of choice pattern on the overall rates of modifiable, $F(3, 63) = 31.7$, $p < .001$, $\eta^2 = .60$, and teleological explanations, $F(3, 63) = 5.47$, $p < .005$, $\eta^2 = .21$, but not stable explanations, $F(3, 63) = 0.38$, ns. The function-and-habitat group made more modifiable and more teleological explanations than both the no rearing and habitat-predictive-only groups and marginally more than the function-predictive-only group (ps $< .10$). The no rearing group made the fewest modifiable explanations, with the habitat-predictive-only groups making more than the no rearing group, and the function-predictive-only group making more than both of these groups.

3.3. Discussion

The purpose of this study was to test whether undergraduates' reasoning about the heritability of *internal* physical properties would differ based on their functional implications and associations with habitat, as was the case for the *external* properties tested in Study 1. The results were similar to Study 1—participants exhibited a strong birth-parent bias overall, but this bias was lessened when the properties in question had functions or habitat associations. Also, as in Study 1, participants' explanations were consistent with their choices (appealing to the biological, genetic, or stable nature of the property for birth-parent choices versus the modifiable or teleological nature of the property for rearing-parent choices), and teleological explanations were most frequent when the properties in question had functional implications. We also found individual difference patterns similar to those in Study 1, with participants who made rearing-parent choices in both predictive conditions also showing the greatest error rates in their inheritance reasoning (i.e., more modifiable and teleological reasoning).

These results, together with Study 1, provide further evidence that undergraduates often apply a purpose-based stance to their reasoning about properties with functional and habitat implications. Moreover, in this study, purpose-based reasoning was found even when the properties were internal and thus presumably less subject to direct modification. This suggests that, in their purpose-based reasoning, undergraduates view the underlying mechanism as stemming from the nature of the property as serving a purpose, and not intentionality per se (e.g., that biological or evolutionary processes somehow cause the needed property change). This is also supported by the fact that we did not see any intentional teleological explanations in our initial coding of the explanation data; all teleological explanations were also non-intentional.

Nevertheless, a noteworthy finding across these two studies is that the effects of function and habitat information were greater in Study 1, when the properties in question were external. Specifically, participants were less likely to judge that the baby would be like its rearing parent on the functional and habitat-linked property dimensions in this study compared to Study 1. Thus, undergraduates' purpose-based stance appears to be sensitive to the nature of the property. They view internal features as more essential and unchangeable and therefore less likely to change due to purpose and necessity, relative to external properties.

4. Study 3

In Study 3, we tested an alternative explanation for the effects seen in Studies 1 and 2. Specifically, it is possible that participants reasoned differently in the predictive conditions because they had more information about the properties in these conditions, making the distinction between the birth and rearing parents and their environments more salient. Moreover, the additional information indicated that the properties had causal or correlational links with other properties, and it may be that linking a property to another

property is sufficient to promote purpose-based reasoning. In other words, learning that "property X causes property Y" may prompt thinking that property X must therefore have a critical purpose. In contrast, in the non-predictive vignettes, no additional information was provided that might prompt consideration of mechanisms other than genetic inheritance. To test this alternative explanation in Study 3, we altered the vignettes such that the properties in question were still linked to other properties, but not to functional outcomes or habitats. Thus, the properties still had predictive power but were not related to the baby animal's survival in any way. If the purpose-based reasoning seen in Studies 1 and 2 is due to this alternative explanation, then the effects obtained earlier should replicate. In contrast, if the purpose-based reasoning is truly driven by the purpose and necessity of the property for the young animal in its rearing environment (i.e., due to the property's function or links to habitat), then the effects should disappear in Study 3 when the properties are no longer purposeful.

4.1. Method

4.1.1. Participants

Participants were 63 undergraduates (18–22 years; 32 males and 31 females) enrolled in an introductory psychology course at a large university in the Midwestern USA. They completed the study for course credit. One additional participant was tested but was excluded due to experimenter error. They self-identified their racial/ethnic background as follows: 41 White, 11 Asian, 5 African American/Black, 5 Hispanic or Latino, and 1 Native American.

4.1.2. Materials and procedure

Participants were given a booklet containing 16 adoption vignettes. The instructions and general format of the vignettes were identical to Studies 1 and 2. However, in this study, *causal* vignettes replaced the function-predictive vignettes and *correlational* vignettes replaced the habitat-predictive vignettes. The causal and correlational links were created by pairing the external property pairs from Study 1 with the internal property pairs from Study 2 (Table 6). In the causal vignettes, the parents' contrasting internal substances were described as causing their contrasting external properties. In the correlational vignettes, the contrasting internal properties were associated with the contrasting external properties. No further implications of the properties were provided in either condition.

The non-predictive vignettes were similar to Study 2. In the causal block, the internal and external properties were not causally linked and were described as having no specific function (e.g., "Look—Clee has a short tail….Clee has something called ronocyte in her heart. The ronocyte doesn't do anything. It just stays there in her heart."). In the correlational block, the contrasting external properties were linked to the same internal properties (e.g., both animals with short tails and animals with long tails have flat bones).

At the end of each vignette, participants were asked to judge whether the baby (at age 6) would have the same property as the birth or rearing parent and to provide an explanation for their choice. As in Studies 1 and 2, in the causal block, participants were asked to judge the baby's outcome on the causal property in the specified causal chain (the

Table 6
Examples of the causal and correlational property descriptions (Study 3)

Property Pair	Causal Description	Correlational Description
Short tail versus Long tail	Ronocyte in heart makes her tail short	Animals with short tails have flat bones
	Kestin in heart makes her tail long	Animals with long tails have round bones
Spotted versus Striped	Farium in bones makes her skin spotted	Animals with spots have a green brain
	Mastin in bones makes her skin striped	Animals with stripes have a yellow brain
Curved toes versus Sharp claws	Zeride in blood makes her toes curved	Animals with curved toes have a kidney in their body
	Dorvus in blood makes her claws sharp	Animals with sharp claws have an appendix in their body

internal substances in this case) and, in the correlational condition, they were asked to make judgments about the predictive property (the external properties in this case).

Half of participants completed a between-category version of the booklets and half completed a within-category version. The vignette ordering and counterbalancing procedures were identical to Study 1.

4.2. Results

4.2.1. Birth choices

Overall, participants showed a very robust birth bias, with the number of birth choices exceeding chance (0.5) in all vignette variants (causal: $M = 0.98$, $t(62) = 50.49$, $p < .001$; correlational: $M = 0.96$, $t(62) = 27.15$, $p < .001$; non-predictive: $M = 0.96$, $t(62) = 33.84$, $p < .001$). To see if this bias varied in strength depending on the predictive nature of the property, we conducted a repeated measures ANOVA on the number of birth-parent choices with vignette version (causal, correlational, non-predictive) as a within-subject factor and block order (causal block first, correlational block first) as a between-subject factor. There were no significant effects.

A large majority of participants (81%) made birth-parent choices exclusively (compared to only 40% in Study 1 and 68% in Study 2). To compare the rate of birth-parent choices across studies, we conducted independent samples t tests. Participants in this study made significantly more birth choices in the causal and correlational conditions than did participants in Studies 1 and 2 in the function-predictive and habitat-predictive conditions, respectively (Study 1 vs. Study 3, $ps < .001$; Study 2 vs. Study 3, $ps < .05$). Thus, participants in this study exhibited the strongest birth-parent bias.

4.2.2. Explanations

For birth-parent choices, the explanation data were analyzed using the same procedure as in Study 1. There was a main effect of explanation type, $F(2, 124) = 1328.4$, $p < .001$, $\eta^2 = .96$, with stable explanations occurring most frequently ($p < .001$). Teleological explanations were rare, occurring never in the causal vignettes, and significantly less than modifiable explanations in the non-predictive vignettes ($p > .05$).

There were too few rearing-parent choices made in this study to conduct explanation analyses (including analyses of individual response patterns). Of the 24 total rearing-parent choices provided in this study, modifiable explanations were provided most frequently, occurring 54% of the time. Stable explanations and teleological explanations were each provided 17% of the time.

4.3. Discussion

Study 3 provided a set of control vignettes to test whether the effects of function and habitat information seen in Studies 1 and 2 (more rearing-parent choices and more modifiable and teleological explanations in the predictive conditions) were driven merely by the provision of causal and correlational property information in the predictive conditions. The current findings do not support this possibility. In this study, when the property dimensions caused or were correlated with other properties, but did not cause functions or were not correlated with habitat specifically, participants' birth bias was unwavering and they did not engage in purpose-based reasoning. Thus, it is not the case that any property that has causal or correlational status is viewed as more modifiable; rather, only those with functions or links to habitat are thought to be less heritable and acquired due to their purpose or necessity.

5. Study 4

The results presented thus far demonstrate that some undergraduates consider it possible for individual animals to acquire properties in a single generation due to the purposeful nature of the property. These findings suggest that, in addition to the larger-scale errors documented in prior research on students' reasoning about evolution (e.g., believing that properties evolve within a species in order to accomplish necessary goals), undergraduates also frequently make fundamental errors in reasoning about property inheritance and acquisition at the individual-organism level. Study 4 directly examined whether undergraduates make a further error at this level: specifically, whether they think that properties acquired due to functions or associations with habitat can then be passed on to second-generation offspring. Prior science education research supports this possibility, as it has shown that undergraduates commonly use Lamarckian reasoning and assume that acquired traits can be passed onto offspring (Brumby, 1979; Ferrari & Chi, 1998; Greene, 1990; Jensen & Finley, 1996). In Study 4, we asked whether this misconception occurs on a smaller, individual-organism level for functional properties. Some prior cognitive development research has shown that preschoolers, but not adults, believe that properties acquired by an organism's birth parents can be inherited by the offspring (Springer & Keil, 1989). However, this has not been tested in an adoption paradigm, or in the case where the property in question serves a purpose in the rearing environment. Thus, this study examined whether the purpose-based reasoning errors observed in Studies 1 and 2 would extend to a larger-scale, Lamarckian reasoning error. Participants

completed the same vignettes as in Study 1, but were also asked, if the baby were to grow up and have a baby of its own, whether its offspring would have the external physical property of the first-generation birth parent or rearing parent.

5.1. Method

5.1.1. Participants

Participants were 48 college students (18–22 years; 22 males and 26 females) enrolled in an introductory psychology course at a large university in the Midwestern USA. They completed the study for course credit. They self-identified their racial/ethnic background as follows: 35 White, 7 Asian, 5 African American/Black, and 1 Hispanic or Latino.

5.1.2. Materials and procedure

Participants read adoption stories similar to those from Study 1. There were eight vignettes total—four in the function block (two function-predictive, two non-predictive) and four in the habitat block (two habitat-predictive, two non-predictive). Block and vignette order were counterbalanced across participants.

The vignettes were identical to the between-category vignettes in Study 1. However, after completing the choice and explanation responses, participants were asked two additional questions. They were first instructed to, "imagine that the baby is now all grown up and just had a baby of its own," and to choose whether the new baby would have the external property corresponding to that of the first-generation birth parent or the first-generation rearing parent. (E.g., "Do you think that the new baby would have long fur or short fur?") They were then asked to provide an explanation.

Each of the eight pairs of drawings depicting the between-category birth and rearing parents appeared once in each test booklet (whereas, in Studies 1–3, they were repeated in each block). The eight property pairs were presented in one of two predetermined orders (e.g., the bumpy skin vs. smooth skin vignette always appeared before the short fur vs. long fur vignette); however, the assignment of property pair to block and predictive status were counterbalanced across participants and block order.

5.2. Results

5.2.1. Birth choices

The proportion of birth-parent choices in each vignette version was calculated separately for the first-generation baby and second-generation baby. t tests showed that participants exhibited a relatively strong birth bias overall, exceeding chance (0.5) in all conditions (all ps > .001). We conducted a repeated measures ANOVA on the number of birth-parent choices with generation (first, second) and vignette version (function-predictive, habitat-predictive, non-predictive) as within-subject factors. Initial analyses revealed no effects of block order, so we exclude it here. There was a main effect of generation, $F(1, 47) = 10.66$, $p < .005$, $\eta^2 = .18$, with more birth-parent choices for the first-generation baby ($M = 0.95$) compared to the second-generation baby ($M = 0.84$). There was

also a marginally significant vignette × generation interaction, $F(2, 94) = 2.47$, $p = .09$, $\eta^2 = .05$; however, planned comparisons did not reveal significantly different effects of vignette across generations. Because there were only two function-predictive and two habitat-predictive vignettes in this study, we collapsed them to increase power and conducted another ANOVA with predictive status (predictive, non-predictive) and generation as within-subject factors. In addition to the generation effect seen in the original analysis, $F(1, 47) = 10.85$, $p < .005$, $\eta^2 = .19$, this analysis revealed a marginally significant main effect of predictive status, $F(1, 47) = 3.64$, $p = .06$, $\eta^2 = .07$, with fewer birth choices on the predictive ($M = 0.87$) than the non-predictive vignettes ($M = 0.92$). There was also a significant predictive status × generation interaction, $F(1, 47) = 5.18$, $p < .05$, $\eta^2 = .10$. The effect of predictive status was significant only for the second-generation-baby choice (predictive: $M = 0.79$; non-predictive: $M = 0.89$), with a reduced birth bias on the predictive vignettes ($p < .05$). There was no effect for the first-generation-baby choice (predictive: $M = 0.94$; non-predictive: $M = 0.95$).

We next compared the frequency of birth-parent choices across Studies 1 and 4. We conducted separate independent samples t tests to compare the rate of birth-parent choices in Study 1 to each of the generation x vignette version combinations in this study. (Only Study 1 participants who were in the between-category condition were included.) For the first-generation choices, there was a significant difference between studies on both the function-predictive vignettes, $t(91) = 2.68$, $p < .01$, and the habitat-predictive vignettes $t(91) = 3.83$, $p < .001$, with participants making more birth-parent choices in this study. For the second-generation choices, there was only a marginally significant difference on the non-predictive vignettes, $t(91) = 1.83$, $p = .07$, with participants making fewer birth-parent choices in this study. Thus, the effects of predictive status on the second-generation choices in this study were comparable to those seen in Study 1.

5.2.2. Explanations

A repeated measures ANOVA was conducted on participants' birth-parent choice explanations with generation (first, second), vignette version (function-predictive, habitat-predictive, non-predictive), and explanation type (stable, modifiable, teleological) as within-subject factors (Table 7). Only participants who made at least one birth-parent choice in all vignette-by-generation combinations ($n = 37$) were included. There was a main effect of explanation type, with stable explanations occurring most frequently, $F(2, 72) = 753.47$, $p < .001$, $\eta^2 = .95$. There was also a vignette × explanation type interaction, $F(4, 144) = 4.02$, $p < .005$, $\eta^2 = .10$, with modifiable explanations occurring most frequently for the habitat-predictive vignettes (habitat-predictive > function-predictive, $p > .05$; habitat-predictive > non-predictive, $p = .07$), and teleological explanations occurring more for the function-predictive vignettes (function-predictive > non-predictive, $p > .05$; function-predictive > habitat-predictive, ns). Lastly, there was a generation × explanation type interaction, $F(2, 72) = 4.06$, $p < .05$, $\eta^2 = .01$, with more stable explanations for first-generation than second-generation birth-parent choices ($p < .001$).

There were very few participants who made rearing-parent choices for both the first- and second-generation baby and/or in both the predictive and non-predictive versions. We

Table 7
Mean frequency of explanation types for birth-parent choices by vignette version and generation (Study 4)

	Explanation Type		
	Stable	Modifiable	Teleological
Function-predictive			
First generation	1.0	0.04	0.07
Second generation	0.91	0.01	0.12
Habitat-predictive			
First generation	0.96	0.16	0.04
Second generation	0.88	0.15	0.07
Non-predictive			
First generation	0.99	0.07	0.03
Second generation	0.91	0.05	0.01

therefore conducted a separate one-way ANOVA on explanation type for each vignette-by-generation combination, and included only participants who made at least one rearing parent choice for that combination. There were no significant effects of explanation type in any of these analyses. Overall, stable explanations were provided for only 16% of rearing-parent choices, while modifiable and teleological explanations were each provided 34% of the time.

5.2.3. Individual differences

We next examined individual differences in participants' explanation and choice patterns, focusing on only second-generation responses as these were most comparable to Study 1. We classified participants as no rearing ($n = 25$), habitat-predictive-only ($n = 6$), function-predictive-only ($n = 6$), and function-and-habitat ($n = 8$), and compared second-generation explanation rates across these groups (in three separate one-way ANOVAs). (Three participants who only made rearing-parent choices on the non-predictive vignettes were excluded from these analyses.) There was a main effect of choice pattern on the overall rates of stable, $F(3, 41) = 16.16$, $p < .001$, $\eta^2 = .54$, and teleological explanations, $F(3, 41) = 10.14$, $p < .001$, $\eta^2 = .43$, but not modifiable explanations, $F(3, 41) = 0.38$, *ns*. The function-and-habitat group made the fewest stable explanations and made more teleological explanations than both the no rearing and habitat-predictive-only groups and marginally more than the function-predictive-only group ($p = .08$). The no rearing group made the most stable explanations. The function-predictive-only and habitat-predictive-only groups did not differ in their rate of teleological explanations, but only the former made significantly more than the no rearing group.

Lastly, a key question of this study was whether undergraduates believe that traits acquired due to purpose or need are believed to be passed onto offspring. We therefore re-coded the second-generation rearing-parent explanations to determine whether they stated specifically that the second-generation baby would inherit a property acquired by the first-generation baby (i.e., exhibited soft inheritance reasoning). There were 23 participants who made at least one-second-generation rearing-parent choice, with a collective total of 62 responses. In the explanations for these choices, 14.5% (9) stated specifically that the

second-generation baby would inherit a trait acquired by the first-generation baby. An additional 29% (18) of the explanations mentioned inheritance, but did so by stating that the first-generation baby would mate with an animal of the same kind as the rearing parent, allowing the second-generation baby to inherit the rearing parent's property. Of the remaining explanations, 21% (13) stated that second-generation baby would acquire the property in its lifetime (e.g., due to teleological factors) and 35.5% (22) did not clearly identify the process involved (i.e., beyond those captured in the original coding).

5.3. Discussion

The results of Study 4 revealed interesting patterns when undergraduates were asked about second-generation offspring. Participants' judgments regarding the second-generation baby were similar to Study 1—they made more rearing-parent choices when the properties had functions or associations with habitat, and they provided more teleological explanations for properties with functions. We also found similar individual response patterns for the second-generation responses, with participants who made rearing-parent choices in both predictive conditions providing the highest rate of teleological reasoning errors and the lowest rate of accurate scientific reasoning. However, in contrast to Study 1, when judging the outcome for the first-generation baby, participants exhibited a strong birth-parent bias that was unaffected by functional or habitat implications. Hence, adding questions about a second generation nullified the effect of predictive status on first-generation judgments. This pattern of results suggests that undergraduates believe that acquiring a property due to its function or habitat associations becomes more probable the longer a species spends in the environment where the property is relevant, and/or once there is a generation that is actually born in that environment. In addition, some participants explicitly appealed to a soft inheritance process (i.e., the inheritance of acquired properties)—a belief that is inconsistent with modern evolutionary theory. Taken together, these findings suggest that undergraduates' reasoning errors about the inheritance of functional or habitat-predictive properties at the individual-organism level (observed in Studies 1 and 2) extend to their reasoning about inheritance at the cross-generation, species-wide level. Thus, at least for some undergraduates, the fundamental misconceptions about evolutionary change documented in the science education research extend to misconceptions at a much more basic level about the mechanisms that guide the inheritance and acquisition of properties within individual organisms.

6. Study 5

In Study 5, we asked whether undergraduates' purpose-based inheritance reasoning would extend to real categories that exist on Earth. Studies 1–4 examined undergraduates' inheritance reasoning for novel categories (living on another planet) to encourage them to rely strictly on their understanding of inheritance rather than any prior category knowledge. Undergraduates frequently used purpose-based reasoning in their inheritance judgments for the novel categories. However, it is possible that these effects would not

extend to real-world contexts. For example, participants might have reasoned that inheritance and evolution can operate differently on a fictitious planet than they do on Earth, such as allowing for purpose-based property acquisition. In contrast, undergraduates might rely strictly on scientific knowledge of inheritance and evolution in their reasoning about real-world categories and thus consider purpose-based property change to be improbable. To test this possibility, participants in Study 5 completed a procedure similar to Study 1, but were asked about real animals that live on Earth and were asked to use their knowledge of science and evolution when answering the test questions.

6.1. Method

6.1.1. Participants

Participants were 47 college students (18–23.5 years; 29 males and 18 females) enrolled in an introductory psychology course at a large university in the Midwestern USA. They completed the study for course credit. They self-identified their racial/ethnic background as follows: 37 White, 9 Asian, and 1 Hispanic or Latino.

6.1.2. Materials and procedure

The procedure was similar to Study 1 with some key differences. First, the images of the birth and rearing parents in each vignette were colored photographs of real animals. A list of the animals is provided in Table 8. To reduce the likelihood that participants would rely predominantly on prior category knowledge, none of the depicted animals was from highly familiar categories (e.g., none was common pets or farm animals). As in Study 1, participants completed either a within-category or between-category condition. In the within-category condition, the birth and rearing parents were the same kind of animal (e.g., two lizards) but differed on the given property dimension (e.g., green vs. blue skin) and were labeled with different proper names (e.g., Clee, Murb). In the between-category condition, the birth and rearing parent were from different animal species (e.g., lizard, iguana) and differed on the given property dimension. Animal class was kept constant within each between-category pair (e.g., reptiles were paired with reptiles, and mammals were paired with mammals). The animals were labeled with their real category labels (scientific names were used when common names were too familiar). Second, participants were explicitly instructed that they would be seeing "real animals that live on Earth" and were asked to use their "knowledge about the world, such as knowledge of science and evolution" when answering the questions. Third, unlike Study 1, the function- and habitat-predictive conditions were tested between-subjects to eliminate the possibility of any carry-over effects across conditions (i.e., as in the interaction between vignette and block order on choice responses in Studies 1 and 2). Participants in the *function* condition ($n = 24$) completed four function-predictive and four non-predictive vignettes, and participants in the *habitat* condition ($n = 23$) completed four habitat-predictive and four non-predictive vignettes. The vignettes were presented in one of two random orders. All other aspects of the materials and procedure were identical to Study 1, including the information about function and habitat provided in the predictive vignettes.

Table 8
Animals used in the within- and between-category conditions in Study 5

Property Pair	Within-Category	Between-Category
Bumpy skin* versus Smooth skin	Pardalis (Chameleon)	Bufo (Toad)
Short tail versus Long tail*	Papionini (Macaque)	Jaguarundi
Spotted* versus Striped	Caudata (Salamander)	Lepidophyma (Lizard)
Curved toes versus Sharp claws*	Talpida (Mole)	Agouti
Long fur* versus Short fur	Hircus (Goat)	Ovibos (Musk ox)
Green skin* versus Blue skin	Lacertilia (Lizard)	Squamata (Iguana)
Straight mane versus Curly mane*	Markhor	Capra (Angora goat)
Pointy ears* versus Floppy ears	Suida (Hog)	Bilby

Notes. Participants saw the names that are not in parentheses; common names are provided in parentheses but were not provided in the task. Asterisks indicate which property value was represented by the item in between-category column.

6.2. Results

6.2.1. Birth choices

Participants exhibited a strong birth bias overall; the rate of birth-parent choices exceeded chance in all conditions (function-predictive: $M = 0.90$, $t(23) = 9.35$, $p < .001$; habitat-predictive: $M = 0.91$, $t(22) = 10.22$, $p < .001$; non-predictive: $M = 0.98$, $t(46) = 37.43$, $p < .001$). We next conducted a mixed ANOVA with condition (function, habitat) as a between-subject factor and vignette version (predictive, non-predictive) as a within-subject factor. (There were no effects of vignette order in this study and it is thus eliminated from the reported analyses.) There was a main effect of vignette version, $F(1, 45) = 5.96$, $p < .05$, $\eta^2 = .12$. As in Study 1, there was a higher rate of birth-parent choices on non-predictive vignettes ($M = 0.98$) than on predictive vignettes ($M = 0.90$).

To directly compare these data to Study 1, we conducted separate mixed ANOVAs for the function condition and the habitat condition. In each, study (Studies 1 and 6) was a between-subject factor and vignette version (predictive, non-predictive) was a within-subject factor. In the function condition, there was a main effect of vignette, $F(1, 120) = 6.93$, $p < .05$, $\eta^2 = .05$ (predictive < non-predictive), and no interaction with study. In the habitat condition, there was a main effect of vignette, $F(1, 119) = 21.69$, $p < .001$, $\eta^2 = .15$ (predictive < non-predictive), as well as a vignette × study interaction, $F(1, 119) = 5.4$, $p < .05$, $\eta^2 = .04$. The effects of vignette were greater in Study 1; specifically, participants in Study 1 showed a significantly lower rate of birth-parent choices on the habitat-predictive vignettes than did participants in this study ($p < .005$).

6.2.2. Explanations

We examined the explanations for birth-parent choices using a mixed ANOVA with condition (function, habitat) as a between-subject factor and vignette version (predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors. There was a main effect of explanation type, $F(2, 90) = 1795.68$, $p < .001$,

η^2 = .98, with stable explanations (M = 0.96) occurring more frequently than either modifiable (M = 0.03) or teleological (M = 0.02) explanations. Although there was no predictive status × explanation type interaction, planned comparisons showed that teleological explanations tended to occur more frequently on predictive vignettes (M = 0.04) than non-predictive vignettes (M = 0.01; p = .08).

To examine participants' explanations for rearing-parent choices, we focused on the 13 participants who made at least one rearing-parent choice. In their explanations for rearing-parent choices, these participants provided stable explanations 18% of the time, modifiable explanations 36% of the time, and teleological explanations 23% of the time. ANOVAs testing for effects of condition (function, habitat) and explanation type (stable, modifiable, teleological) on rearing-parent choice explanations produced no significant effects.

To directly compare the explanation data to Study 1, we conducted separate mixed ANOVAs for the function and habitat conditions with study (Study 1, Study 6) as a between-subject factor and vignette version (predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors. There were no interactions between explanation type and study, indicating that the explanation patterns were similar across studies.

6.2.3. Individual differences

Because the explanation patterns in this study were similar to Study 1, but the effects were weaker overall, we conducted a more sensitive assessment of the explanation distributions across conditions. We created two categorical variables to classify participants' explanations on the predictive and non-predictive vignettes (collapsed across the function and habitat conditions). For each predictive status, participants were categorized as either "stable only" if they provided all stable explanations or "mixed" if they provided at least one modifiable or teleological explanation. Because comparing the distribution of these categories across predictive status conditions is a paired comparison, we conducted a McNemar's chi-square test. This analysis revealed a marginally significant effect, $\chi^2(1)$ = 3.56, p = .06. Thus, explanation patterns were affected by the predictive status of the properties, with 28% (13) of participants switching from strictly stable explanations on the non-predictive vignettes to some modifiable or teleological explanations on predictive vignettes (28 participants [60%] exhibited a stable only pattern across vignette types, five were stable only on predictive but mixed on non-predictive, and one exhibited a mixed pattern on both).

6.3. Discussion

The results of Study 5 demonstrate that the general patterns seen in Study 1 with novel categories also extend to real categories. When asked to use their knowledge of science and evolution to make inheritance judgments about real animals on Earth, undergraduates showed a strong birth-parent bias, but this bias was lessened when the properties had functions or were associated with habitat. Moreover, when explaining their inheritance

reasoning, participants were more likely to appeal to the teleological nature of the property when it had a function and to either the modifiable or teleological property when explaining how an animal could acquire the same property as its non-biological rearing parent. Although the effects seen in this study were not as strong as those seen when we inquired about novel animals, the current findings nevertheless demonstrate that undergraduates' purpose-based reasoning is not restricted to fictitious categories or contexts and extends to their understanding of inheritance on Earth. This finding is particularly noteworthy given that participants were instructed to use their "knowledge of science and evolution."

7. Study 6

In Study 6, we compared our novice undergraduate sample to individuals with expertise in biology in order to examine whether the purpose-based stance seen in the above studies is grounded in biologically accepted views of inheritance. Prior research has found that, in addition to high school and university students, evolutionary processes are misunderstood by individuals thought to have greater expertise on the subject, such as science teachers (Jungwirth, 1977; Nehm & Schonfeld, 2007; Tidon & Lewontin, 2004). This includes errors similar to those observed in the current research, such as accepting teleological and anthropomorphic explanations of the evolution of species. The fact that misconceptions are evident at a more expert level speaks to the fact that evolution—and the appropriate terminology for conceptualizing it—is a complex process that is highly difficult to understand (and teach). We were therefore interested in seeing whether experts would engage in purpose-based reasoning as undergraduates did when reasoning about property inheritance at the individual-organism level. To examine this, we tested biology professors, professionals, and graduate students using the procedure from Study 1. If we were to find purpose-based reasoning in experts, it would indicate that this is a biologically accepted mode of reasoning about property inheritance. In contrast, if we do not find purpose-based reasoning in experts, it would demonstrate that the undergraduates' errors are not simply a matter of conventional ways of thinking and speaking about evolution, and stem from a greater misconception about the processes involved in property inheritance and acquisition.

7.1. Method

7.1.1. Participants

Participants were 17 individuals with expertise in biology. They were recruited via email and personal contact at three Midwestern universities. Most (13) were biology faculty members with doctoral degrees in biology or related fields (e.g., paleontology); three were graduate students completing their doctoral degrees in biology or related fields; and one had completed all graduate work except for the dissertation and held a professional position in the field. There were 7 males and 10 females. Their average age was 41. (One

participant did not report her age.) They self-identified their racial/ethnic background as follows: 11 White, 2 Asian, 1 Hispanic or Latino, 1 Native Hawaiian/Pacific Islander, and 2 unreported.

7.1.2. Materials and procedure

The test materials and procedure used in this study were identical to the between-category condition in Study 1, except participants were recruited and tested through email. An initial recruitment email was sent to biology graduate students and faculty stating that we were recruiting individuals with advanced training in biology as part of a larger project that included data collection from children and undergraduates without advanced training in biology. Participants who consented to participate were emailed the test booklet as an attachment. They were asked to complete the booklet as soon as possible and return it via email once completed. Of those individuals who were sent a recruitment email, 66% replied and 51% participated. A reminder email was sent to participants if they did not return the booklet within a week of receiving it. Only 1 individual never returned the booklet after receiving reminders. All other aspects of the procedure were identical to Study 1.

7.2. Results

7.2.1. Birth choices

Experts exhibited a robust birth bias that was near ceiling on all vignette versions (function-predictive: $M = 0.99$; habitat-predictive: $M = 0.97$; non-predictive, $M = 0.99$). There were only five rearing-parent choices total (1.8% of all responses), with three occurring on predictive vignettes. A repeated measures ANOVA with vignette version as a within-subject factor revealed no differences across conditions. Independent sample t tests comparing the rates of birth-parent choices in Study 1 (between-category condition only) to the expert sample revealed significant differences in the function-predictive, $t(64) = 2.3$, $p < .05$, and habitat-predictive conditions, $t(64) = 3.29$, $p < .005$, with stronger birth-parent biases in the expert sample.

7.2.2. Explanations

We conducted a repeated measures ANOVA on birth-parent choice explanations with vignette version (function-predictive, habitat-predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors. There was a main effect of explanation type, $F(2, 32) = 266.97$, $p < .001$, $\eta^2 = .94$. Stable explanations ($M = 0.97$) occurred more frequently than either modifiable ($M = 0.17$) or teleological ($M = 0.02$) explanations (ps < .001), and teleological explanations occurred least frequently (teleological < stable: $p < .001$; teleological < modifiable; $p < .05$). There was also a vignette × explanation type interaction, $F(4, 64) = 5.24$, $p < .005$, $\eta^2 = .25$. The high frequency of stable explanations and the low frequency of teleological explanations were consistent across vignettes. Modifiable explanations, however, were provided more on the habitat-predictive vignettes than on the non-predictive vignettes and were more frequent than teleological explanations on the habitat-predictive vignettes (ps < .05).

To compare birth-parent choice explanations in the expert sample to the undergraduates in Study 1, we conducted a repeated measures ANOVA with expertise (expert, undergraduate) as a between-subject factor and vignette version (function-predictive, habitat-predictive, non-predictive) and explanation type (stable, modifiable, teleological) as within-subject factors. Only undergraduates in the between-category condition who made at least one birth-parent choice in all three vignette versions were included ($n = 44$). There was a three-way expertise × vignette × explanation type interaction, $F(4, 236) = 2.99$, $p < .05$, $\eta^2 = .04$. Experts provided more modifiable explanations in both function- and habitat-predictive vignettes.

There were too few rearing-parent choices in the expert sample to conduct analyses on their explanations. Of the explanations provided for rearing parent choices, three included a stable explanation, two included a modifiable explanation, and two included a teleological explanation.

7.3. Discussion

Biology experts showed a very robust birth bias that was unaffected by the functional or habitat implications of the property in question, as it was for undergraduates. In their explanations, experts appealed overwhelmingly to biological or genetic mechanisms. Although experts also occasionally appealed to the modifiable nature of the properties, this was rarely associated with rearing-parent choices and, most importantly, they rarely mentioned teleological factors. This is in contrast to the undergraduates, who repeatedly provided teleological explanations for property inheritance and acquisition in the studies reported above, particularly when considering properties with functional implications. These findings demonstrate that the purpose-based stance exhibited by undergraduates in the current research has no foundation in biologically accepted reasoning.

8. Study 7

Study 7 was designed to examine the role of age (i.e., maturation and experience) in purpose-based reasoning, testing preschoolers in a procedure similar to Study 1. One possibility is that children, like undergraduates, hold a purpose-based stance of functional properties. Teleological explanations are pervasive in young children's thinking about the world, so much so that Kelemen (1999) has described children as having a "promiscuous teleology" that leads them to interpret objects and events as intentional, purposeful, or goal-directed. Hence, it may be that this early-emerging teleological stance is also applied in the context of inheritance reasoning and, consequently, that children will exhibit a purpose-based stance of functional and habitat-predictive properties as did undergraduates.

An alternative possibility is that children have more of an inheritance-of-essentials stance than undergraduates. Children have strong essentialist tendencies, as demonstrated on several different tasks (Gelman, 2003). They view categories as consisting of members with innate similarities that exhibit stability and retain their category membership across

superficial transformations. Moreover, young children have exhibited an inheritance-of-essentials stance when reasoning about functional properties in other paradigms. In particular, Springer and Keil (1989) found that 4- to 5-year olds were more likely to say that a property would be passed from parent to offspring if that property had an important function (e.g., a kind of heart that makes the animal stay healthy), regardless of whether the property was internal versus external, or inborn versus acquired. In contrast, adults gave the highest priority to inborn properties. The 6- to 7-year olds showed some evidence of both modes of reasoning, thus demonstrating a developmental shift from prioritizing functional properties to prioritizing inborn properties in judgments about heritability. Thus, it may be that, only with increasing age, are functional properties viewed as less heritable and more open to change as needed. This study examines whether this is the case even in the context of an adoption paradigm where the properties in question have functional implications or habitat associations in the young animal's rearing environment, and thus may be more likely to promote purpose-based reasoning.

8.1. Method

8.1.1. Participants

Participants were 48 preschoolers (48–66 months, $M = 57$). Approximately, half were boys (23) and half were girls (25). One additional child was tested but was excluded from the final sample because she had apparent difficulty understanding the task. Most participants were recruited from preschools and daycare centers in Ann Arbor, MI and surrounding communities. A brief letter describing the study and consent form was distributed to parents of children in the targeted age range at the participating facilities. Some participants were also recruited via direct mailings and follow-up phone calls to families in the area. Only children whose parents gave consent were included. Racial and ethnic background information was not obtained.

8.1.2. Materials and procedure

Participants were tested individually in a quiet space in their preschool during school hours or in an on-campus laboratory. The materials were similar to those used in the between-category condition in Study 1. However, some changes were made so that the procedure would be appropriate for young children. First, the adoption stories were read aloud to children. The experimenter instructed the child that she was going to tell them stories about animals that live on a planet that is far away. They were told that they would see pictures of some of the animals and would be asked questions about the animals. The experimenter then began reciting the first vignette. The content of the vignettes was identical to Study 1. At the beginning of each vignette, the experimenter placed two laminated drawings on the table in front of the child, one of the birth parent and one of the rearing parent. The experimenter pointed to each picture as she referred to them throughout the vignette. Unlike the adult version of this task, in the child version, a picture of a baby cradle was used to portray the baby to help children keep track of the story. The cradle provided a clear cue without providing any information about what the

baby might actually look like. This picture was placed on the table when the baby was first mentioned in each vignette and the experimenter pointed to it whenever she referred to "the baby." The same baby cradle picture was used for all of the vignettes.

Children were asked comprehension questions after the adoption scenario in each vignette to ensure that they were following them. The experimenter asked the following: (1) "So, whose tummy did the baby come out of, the [birth-parent name]'s or the [rearing-parent name]'s?" (2) "And who does the baby live with now, the [birth-parent name] or the [rearing-parent name]?" If the child answered both questions correctly, the experimenter continued the story. If the child answered at least one question incorrectly, the experimenter repeated the story and the comprehension questions (this occurred on 10 trials total: 1 trial for each of 10 participants). In one of these cases, the child answered the questions incorrectly again, and the experimenter told the child the correct answers before continuing.

As with the undergraduates, at the end of each vignette, children were asked to choose whether they thought the baby (now 6 years old) had the same external physical property as the birth parent or the rearing parent (e.g., "Do you think that the baby has long fur like the lep or short fur like the vit?"). They were not asked to explain their responses, because we assumed it would be difficult for preschoolers to articulate their reasoning.

The function-predictive and habitat-predictive conditions were manipulated between subjects. Half of the children were in the function condition, which included four function-predictive and four non-predictive vignettes. The other half were in the habitat condition, which included four habitat-predictive and four non-predictive vignettes. The predictive and non-predictive vignettes were blocked in each condition; half of the children completed the predictive block first and half completed the non-predictive block first. Prior to testing, the eight external property pairs were randomly divided into two groups of four. The assignment of these groups to block order (first, second) and predictive status (predictive, non-predictive) was counterbalanced.

8.2. Results

One-sample t tests showed that the rate of preschoolers' birth-parent choices was greater than chance (0.5) for all vignette variants (all $ps \leq .05$) except for the non-predictive vignettes in the function condition. To examine whether their bias was significantly affected by a property's predictive status, we conducted a mixed ANOVA on the rate of birth-parent choices with condition (function, habitat) as a between-subject factor and predictive status (predictive, non-predictive) as a within-subject factor. Initial analyses revealed no effects of block order, so it is excluded here. There was a significant condition × predictive status interaction, $F(1, 46) = 5.23$, $p < .05$, $\eta^2 = .10$. None of the pairwise comparisons was significant (both $ps \geq .10$ for predictive vs. non-predictive in both function and habitat). However, the interaction shows that the effects of predictive status worked in opposite directions across the function and habitat conditions—whereas linking a property to habitat led to a tendency to judge that animals would become more like the rearing parent (predictive: $M = 0.67$; non-predictive: $M = 0.74$), ascribing a function to a property had the reverse effect (predictive: $M = 0.68$; non-predictive: $M = 0.60$).

We directly compared children's responses to the undergraduates in Study 1 (including only the 49 undergraduates who had completed the between-category condition). We conducted a separate mixed ANOVA for each condition/block (function, habitat) with age (child, undergraduate) as a between-subject factor and predictive status (predictive, non-predictive) as a within-subject factor. In the function condition, there was a main effect of age, $F(1, 71) = 13.58$, $p < .001$, $\eta^2 = .16$, and an age × predictive status interaction, $F(1, 71) = 7.7$, $p < .01$, $\eta^2 = .10$. Undergraduates made more birth parent choices overall ($M = 0.88$; children: $M = 0.64$) and the effect of predictive status (function-predictive < non-predictive) was significant only in the undergraduate sample ($p < .01$). In the habitat condition, there was again a main effect of age, $F(1, 71) = 4.05$, $p < .05$, $\eta^2 = .05$, with a greater overall birth bias in the undergraduate sample ($M = 0.83$; children: $M = 0.70$). There were also main effects of predictive status, $F(1, 71) = 20.02$, $p < .001$, $\eta^2 = .20$, and an age × predictive status interaction, $F(1, 71) = 6.91$, $p < .05$, $\eta^2 = .07$. Across age groups, there were more birth-parent choices for the non-predictive than the habitat-predictive vignettes. However, planned comparisons on the interaction showed that the effect of predictive status (habitat-predictive < non-predictive) was significant only for undergraduates ($p < .001$).

8.3. Discussion

The results of Study 7 show that, like undergraduates, preschoolers exhibit an overall birth bias when reasoning about the inheritance of external physical properties. They predicted that the baby would be like its birth parent at a rate that exceeded chance in nearly all conditions. Similar to undergraduates, preschoolers' birth bias was affected by the properties' functional and habitat implications. However, the robustness and direction of these effects differed across the two age groups. The effects of both functional and habitat implications on preschoolers' inheritance judgments were weaker, but they tended to view function-predictive properties as more heritable and habitat-predictive properties as less heritable than non-predictive properties. The effect of function was in the opposite direction as it was for undergraduates, who viewed functional properties as less heritable than non-predictive properties. This pattern is consistent with prior cognitive development research showing that functional properties are seen as more heritable at younger ages (Springer & Keil, 1989), and suggests that young children hold an inheritance-of-essentials stance of functional properties—they view them as more central and, thus, more heritable. This stance was tenuous in this study, however, suggesting that preschoolers may not have a dominant approach for thinking about inheritance mechanisms for functional properties.

In contrast, the effect of habitat information was similar across preschoolers and undergraduates. Like undergraduates, preschoolers tended to view habitat-predictive properties as less heritable than non-predictive properties. This pattern is consistent with a purpose-based stance of properties that are associated with habitat. That is, properties with links to habitat are viewed as less heritable and more modifiable because they might serve some purpose in the animal's environment. However, as with preschoolers'

judgments about functional properties, the effects for properties with links to habitat were marginal, suggesting that preschoolers may also not have a dominant approach for reasoning about the inheritance of properties with habitat implications.

9. General Discussion

9.1. Summary of results

This research provides insight into purpose-based reasoning about inheritance and the factors that promote this reasoning, including the type of property being considered, age, and level of expertise. Studies 1–3 and 5 demonstrate that undergraduates often use a purpose-based stance to reason about properties with functional or habitat implications. Although undergraduates were inclined to view physical properties as inherited and stable, they also tended to reason differently about properties that had functional or habitat implications and thus might serve an important purpose and influence an animal's survival. In these cases, the possibility of an animal acquiring a property in its lifetime became more plausible. This process was often attributed to teleological factors, such as the function or necessity of the property.

Our findings are particularly interesting given that undergraduates exhibited a purpose-based stance in several contexts that might be expected to deter it. First, the vignettes in these studies were strongly biased towards nativist responses. Specifically, the vignettes concerned physical properties (not situational, social, or psychological properties) and provided no information about social processes such as teaching or modeling, making it likely that one would rely on a default assumption of genetic inheritance. Moreover, participants were never given explicit information about the importance of the properties to the young animal's survival in its rearing environment (i.e., whether the young animal's survival would be contingent on its ability to perform the functions or match its habitat). It is therefore striking that we observed *any* rearing-parent choices and teleological reasoning. Remarkably, more than 1 in 3 undergraduates across Studies 1 and 2 (where rearing-parent choices were most likely) used teleological reasoning at least once (Study 1: 49%; Study 2: 26% of participants), suggesting that it is a highly available explanatory framework, especially when reasoning about functional properties.

Second, we found the same patterns regardless of whether the properties were external (Study 1) or internal (Study 2). In the latter case, one might expect that properties would be viewed as considerably less modifiable. The fact that we still found evidence of purpose-based reasoning with internal properties demonstrates that purpose-based property modification is not attributed solely to intentional or agentive mechanisms. Rather, the purpose or necessity of the property alone is viewed as a sufficient mechanism.

Third, we found evidence of purpose-based reasoning with both novel and real non-human animal categories (Study 5). Notably, however, purpose-based reasoning was relatively stronger with novel categories, suggesting that undergraduates' inheritance reasoning deviates from accepted scientific ideas more so when considering novel categories.

This is consistent with prior research showing that undergraduates are most accurate in their reasoning about evolution (e.g., applying key concepts, such as trait variation) when considering familiar categories (Evans et al., 2010; Opfer, Nehm, & Ha, 2012). Nevertheless, even in these contexts, students often continue to also apply naïve cognitive biases (e.g., teleology) as we observed in Study 5. Future research is needed to better understand why familiarity influences inheritance and evolutionary reasoning. One possibility is that familiar category knowledge promotes accurate reasoning (Nettle, 2010).

Fourth, we found the same effects regardless of whether the offspring's birth and rearing parent were the same kind of animal (within-category condition) or different kinds of animals (between-category). That is, acquisition of properties with functional or habitat implications was thought to be possible even when the new property was exhibited only by a member of a different kind. Thus, purpose-based reasoning overrode any consideration of shared category membership. This result is inconsistent with prior research showing that students use more naïve evolutionary reasoning (e.g., attributing change to teleology or intentionality) in between-species contexts and more key scientific concepts in within-species contexts (Nehm & Ha, 2011). Although it is not yet clear why this distinction exists for species-level reasoning, our findings suggest that any advantages gained by considering within-category comparisons at the species-level do not stem from understanding inheritance per se.

One notable limitation of the current research is that we manipulated predictive and non-predictive status within-subjects, and this may have exaggerated the obtained effects. We found few effects of block order (Study 1, as well as a marginal effect in Study 2), but they suggest that participants tended to shift towards purpose-based reasoning as they proceeded through the vignettes. The contrasts between the information provided across conditions may have encouraged participants to think differently about each vignette and consider a greater variety of explanatory possibilities. Future research would be needed to determine whether undergraduates think differently about property inheritance and acquisition when properties are queried in isolation versus in the context of being queried about other types of properties.

Despite this limitation, the finding that undergraduates use purpose-based reasoning at all has important implications. The purpose-based stance exhibited by undergraduates in the current research is consistent with students' teleological reasoning about microevolution concepts seen in prior science education research. The current work extends the prior research in an important way by demonstrating that undergraduates also often exhibit purpose-based reasoning when considering inheritance at the level of individual organisms. At least some undergraduates believe it possible for an animal to acquire a physical property in its lifetime provided that the property has a useful function or is the best fit for its habitat. Like teleological reasoning about microevolution, this belief is inconsistent with principles of Darwinian evolution, whereby organisms do not simply acquire properties as needed. Our findings therefore demonstrate that students' teleological reasoning errors are not restricted to larger-scale aspects of evolution; misconceptions also frequently occur at a more basic level. Thus, teleological reasoning does not seem to simply constitute an intuitive or short-hand way of thinking or talking about the complexities of evolutionary change in that it can also extend to fundamental misconceptions about the processes

underlying property inheritance and acquisition. Further insight into this issue was provided in Study 4, where we asked whether undergraduates would extend the notion that animals can acquire purposeful properties in their lifetime to the belief that traits acquired in this manner can be passed onto offspring. Although only 8% of participants specifically exhibited soft inheritance reasoning, the fact that we found any errors of this sort demonstrates the possibility for significant reasoning errors about inheritance to develop at the individual-organism level.

9.2. Reasoning errors about evolution versus reasoning errors about inheritance

Further research is needed to determine the precise causal relation between reasoning errors at the individual-organism level and those at the species-level. One possibility is that misunderstandings about inheritance at a lower-level lead to broader misunderstandings about evolution. For example, teleological reasoning about property inheritance acquisition might be extended to reasoning about changes within and across species more broadly (e.g., that an animal will inherit or acquire properties as needed, and will then pass needed properties onto its offspring). However, this seems unlikely based on the fact that, in the current research, we found relatively lower rates of teleological reasoning relative to prior studies examining microevolution. In some studies, 25% or fewer participants have demonstrated accurate evolutionary reasoning (e.g., Bishop & Anderson, 1990; Jensen & Finley, 1995), whereas more than half of our participants did. This suggests that grosser misconceptions are evident when reasoning about evolutionary changes on a larger scale (particularly with between-species comparisons, as mentioned above). Thus, a more likely possibility is that, as misunderstandings about evolution develop, they trickle back down to reasoning about inheritance at the individual-organism level. For example, when considering inheritance, undergraduates may apply larger-scale misconceptions about evolution (e.g., that species "evolve" and "adapt" in accordance with selection pressures, which allows an individual animal to inherit or acquire whatever it needs). The results of Study 4 lend further support to this second possibility in that they demonstrate that undergraduates' inheritance reasoning may incorporate consideration of the timescale involved. Specifically, when we added information about second-generation offspring to the adoption scenarios, participants found it plausible that the second-generation offspring could acquire properties with functional and habitat implications, but this effect dissipated for the first-generation baby. Thus, undergraduates might believe that acquiring a property due to its function or habitat associations becomes more probable the longer a species spends in the environment where the property is relevant, and/or once there is a generation that is actually born in that environment. Although this represents an error about the timescale required for evolutionary change (as it is not the case that an animal will necessarily acquire a property that suits its environment because it is born in that environment or because its parent grew up there), it also suggests that undergraduates are sensitive to the fact that evolution takes time, which then influences their inheritance reasoning. This supports the possibility that errors in reasoning about evolution feed back to reasoning about inheritance (at least for some undergraduates).

One way to further examine these possibilities in future research would be to ask undergraduates more in-depth questions to probe their understanding of inheritance and evolution. Participants' explanations in the current research were often very brief and lacking explanatory detail. More detailed responses might indicate more clearly how their understanding of inheritance relates to their understanding of evolution more broadly (e.g., see Rector, Nehm, & Pearl, 2012). Moreover, this would also allow for a more nuanced analysis of explanatory frameworks for inheritance. For example, our teleological explanations category included subtypes (e.g., need, adaptation, purposefulness) that may constitute more distinct groupings if explained more fully.

9.3. Novice versus expert reasoning about inheritance

The magnitude of undergraduates' reasoning errors was elucidated in Study 6, where we found no teleological reasoning among biology experts. In addition, although experts often appealed to the modifiable nature of properties in their explanations, this did not lead them to make rearing-parent choices, as it often did for the undergraduates. Thus, undergraduates' purpose-based reasoning about property inheritance at the individual-organism level is not founded in accepted biological knowledge. Prior findings regarding the effects of expertise on evolutionary reasoning have been mixed. Some prior research has found no effect of expertise, with both non-experts and experts accepting teleological explanations (Jungwirth, 1977; Nehm & Schonfeld, 2007; Tidon & Lewontin, 2004). However, the expert samples in that research mostly consisted of secondary school teachers, whereas the experts in the current research had more extensive formal training in biology and evolution specifically. Consistent with this distinction, a more recent study (Nehm & Ridgway, 2011) compared university students to an expert sample that consisted primarily of doctoral-level biologists and found that experts were more likely to use scientific concepts and avoid naïve cognitive biases (e.g., teleological explanations) in their evolutionary reasoning (see also Gregory & Ellis, 2009). Other research suggests that evolution concepts may vary in accuracy across levels of expertise (e.g., science education faculty at universities found teleological explanations less acceptable than did prospective or practicing teachers; Jungwirth, 1977). It would be interesting for future research to compare more precisely microevolution concepts and inheritance reasoning across various levels of expertise. The current work suggests that at least one key distinction between expert and non-expert concepts of evolution may be in understanding how properties are inherited and acquired at the individual level.

Nevertheless, intuitive teleological biases may exist to some extent at all levels of expertise. A recent study by Kelemen and her colleagues (Kelemen, Rottman, & Seston, 2012) showed that individuals with doctoral degrees in the physical sciences resorted to teleological reasoning when their cognitive resources were taxed. Specifically, they were more willing to accept teleological explanations of natural phenomena under a speeded condition, when they presumably had less time to suppress unwarranted biases, compared to a non-speeded control condition. Thus, even with years of scientific experience, individuals may use teleological reasoning as a default explanatory framework. Interestingly,

Kelemen et al. found the same effects with humanities scholars, suggesting that it is education in general, not science education per se, that reduces teleological tendencies. It would be interesting to extend this research to the biological domain to assess whether individuals with extended expertise in the domain of biology continue to hold intuitive teleological biases about inheritance and evolution.

9.4. The development of purpose-based reasoning

A key question that these effects with expertise raise is how biases such as the purpose-based stance of property inheritance and acquisition seen in the current research emerge. Study 7, in which we tested preschoolers, sheds some light on this question. Like undergraduates, preschoolers exhibited a relatively strong bias toward viewing external physical properties as inherited, but their judgments were also affected to some degree by the functional and habitat implications of the properties. Specifically, the interaction between predictive status and condition suggested that preschoolers view function-predictive properties as more heritable than non-predictive properties, whereas they view habitat-predictive properties as less heritable than non-predictive properties. These response patterns differed from undergraduates'. Whereas undergraduates often exhibited a purpose-based stance for properties with both functional and habitat implications (judging that both were more modifiable than properties with no implications), preschoolers' responses suggested that they hold an inheritance-of-essentials stance for functional properties but a purpose-based stance for properties that are associated with habitat.

The influence of function on preschoolers' inheritance judgments contributes to prior research demonstrating early teleological biases in other contexts involving reasoning about evolution and the natural world, such as preschoolers' "promiscuous teleological bias" that leads them to view all kinds of objects (living, natural, human-made) as existing "for" a purpose (Kelemen, 1999), and school-aged children's preference for intentional (i.e., creationist) accounts of the origins of species (Evans, 2000, 2001). In the current research, preschool children likewise viewed functional features as important. In particular, they viewed functional features as ones that are inherent to an organism and thus more likely to be inherited than non-predictive properties. Hence, for young children, ascribing a purpose to a property seems to signal that it is essential.

The opposite effects of functional implications on undergraduates' and preschool children's inheritance judgments suggests that there may be a developmental shift in inheritance reasoning from viewing functional properties as core properties that are stable within categories, to viewing them as useful properties that can be modified as needed. Other work has demonstrated shifts in young children's thinking about function in other contexts, including the development of a "design stance" for artifact concepts (i.e., viewing artifacts is being intentionally designed for a specific purpose) and the emergence of promiscuous teleology (Kelemen, 2012). These shifts seem to occur around age 4 or later. Thus, the 4- to 5-year olds in the current research may have been at an age where reasoning about the role of function in property inheritance and acquisition is in transition. This may be one reason for the relatively weak effect of predictive status on preschoolers'

responses—that is, they may be in the process of learning about various factors that influence heritability.

One possible factor that may contribute to the further development of purpose-based reasoning about inheritance is exposure to teleological language—in biological contexts and perhaps even more broadly. Educators often use language to describe evolution that implies intentionality, agency, and goal directedness, and this has been found to be the case with educational materials more broadly (e.g., Jungwirth, 1975). Moreover, students often use such ambiguous terms (e.g., "select," "adapt") without clearly understanding what they mean in a scientific context (Rector et al., 2012). Thus, it is possible that teleological reasoning about inheritance stems in part from experience with teleological language in the context of learning about evolutionary change. One important direction for future research is to develop a method for gathering explanatory data from children, as we did with undergraduates, to better understand their beliefs about the inheritance of properties with functional and habitat implications and how these are similar to or different from undergraduates' explanations.

Further examination of the factors contributing to the development of purpose-based reasoning might also provide insight into the individual response patterns seen in the current research. We found variation in the rate of inheritance reasoning errors, ranging from individuals who tended to make rearing-parent choices whenever the properties were predictive, to individuals who made rearing-parent choices when properties were predictive of only function *or* only habitat, to individuals who exhibited a birth-parent bias regardless. Moreover, the scientific accuracy of participants' explanations matched their choice patterns: participants with a rigid birth-parent bias consistently referred to the stable nature of the properties in question, participants with a more flexible bias referred more often to the modifiable or teleological nature of the properties, and participants who made rearing-parent choices whenever the properties were predictive had the highest rate of modifiable or teleological explanations. It is not clear how these individual differences in purpose-based reasoning emerge, and it will be informative for future research to determine what factors contribute to these varied views of inheritance and evolution.

9.5. Implications for biology education

Although it is not clear from the current research when or how purpose-based reasoning emerges, the fact that it exists at all in undergraduates' inheritance reasoning has important educational implications. Prior studies in science education documenting errors in evolutionary reasoning have often examined whether various instructional interventions can lead to improvement. Overall, this research has shown that instruction can be effective at reducing errors such as teleological and Lamarckian reasoning (i.e., inheritance of acquired traits), but the improvement is often modest (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1995, 1996; Nehm & Reilly, 2007; Nehm & Schonfeld, 2007; Settlage, 1994). Our research points to specific ways in which instruction might be more effective.

First, it may benefit students to receive instruction regarding the specific process of inheritance and acquisition of properties at the individual-organism level, given consistent misconceptions at this level. Second, we found purpose-based reasoning to be most frequent for external properties (relative to internal properties), for properties that had clear functions with potential survival implications, and for properties that were associated with habitat and implied purpose. Thus, it may be most helpful for instruction to highlight more specifically what mechanisms can plausibly lead to the acquisition of such properties, and what mechanisms cannot. Third, we found that many undergraduates use multiple frameworks in their inheritance reasoning, including reasoning that is inconsistent with established evolutionary principles (e.g., teleological), as well as reasoning that does not constitute any violation (e.g., appealing to genetic mechanisms). Interestingly, this was the case for both birth- and rearing-parent choices. Thus, even when undergraduates seem to understand the role of biological mechanisms, they may also think that purpose-based change is possible. These findings are consistent with prior work demonstrating that people often reason about evolution using hybrid frameworks that consist of more than one view, typically including both scientific and naïve reasoning (e.g., trait variation and need-based reasoning; natural selection and creationism; Evans et al., 2010; Nehm & Ha, 2011). Hence, students might benefit from instruction that clearly distinguishes between various frameworks and identifies in what contexts each is appropriate (e.g., acclimatization is a plausible form of property modification, but not one that necessarily occurs whenever an organism lacks a property that has an important function or corresponds to its habitat). Indeed, some research has suggested that certain reasoning errors, such as need-based reasoning, might actually be a useful stepping stone towards understanding evolutionary reasoning (i.e., as opposed to more grossly inaccurate cognitive reasoning biases, such as desire-based/anthropomorphic change; Legare, Lane, & Evans, in press; Spiegel et al., 2012). It might therefore be effective to draw out students' teleological reasoning tendencies and clearly distinguish them from the process of individual variation and natural selection in an effort to promote accurate evolutionary reasoning. This may be especially important to address for properties with clear survival-relevant functions, as we found teleological explanations to be especially common in undergraduates' inheritance reasoning for these sorts of properties. Lastly, our findings suggest that instruction may be most effective at younger ages, before inaccurate biases emerge (see also Kelemen, 2012). Together, these instructional techniques may lead to more comprehensive and accurate views of inheritance and evolution, in students of all ages as well as educators.

Acknowledgments

Notes

1. An additional block of eight vignettes was included in Study 1 in which, in half of the vignettes, the birth and rearing parents' contrasting physical properties were described as being inborn and permanent and, in the other half, were described as being acquired and transient. This was included as a control to see whether participants would show a stronger birth bias when the properties were inborn and stable (which they did) and is not discussed further here. The description of Study 1 therefore focuses on 16 of 24 vignettes total that participants completed.

2. In Studies 1–6, participants were also asked to rate how confident they were about their choice on a scale ranging from 1 ("not at all sure") to 7 ("very sure"). Across studies, participants were more confident about birth-parent than rearing-parent choices; however, these data were not a primary focus of the research and are omitted from the results for brevity.

3. The habitat block also included two vignettes in which the contrasting non-obvious property was a characteristic sound (e.g., makes a growling sound vs. makes chirping sound). Initial analyses revealed that participants' rate of rearing-parent choices was substantially higher on these two vignettes (62%) relative to the other vignettes (8%) in the habitat condition, and regardless of predictive status. We assume that this dimension was viewed as particularly malleable or intentionally modifiable (e.g., several participants explained that the baby could learn to imitate its rearing parent). We therefore eliminated the data for these two vignettes from the analyses, and included only data from the remaining six vignettes in the habitat block (i.e., three habitat-predictive versions, and three non-predictive versions for each participant). The same was done in Study 3.

Appendix :
Sample vignettes from Study 1

Long tail versus short tail, function-predictive, between-category

- This is a clee. (Drawing of animal appeared above this statement.)
- This is a murb. (Drawing of animal appeared above this statement.)
- The clee and the murb are different kinds of animals.
- One day, the clee had a baby. That means that the baby came out of the clee's tummy.

- But the clee could not take care of the baby. So, right after the baby was born, it went to live with the murb.
- The clee never saw the baby again. The murb took care of the baby.
- The baby grew up with the murb and now it is 6 years old.
- Look—the clee has a short tail. And guess what—the clee wiggles her short tail to show that she is excited.
- Look—the murb has a long tail. And guess what—the murb waves her long tail to knock bugs off of her back.

Pointy ears versus floppy ears, habitat-predictive, within-category

- This is Tandy. (Drawing of animal appeared above this statement.)
- This is Jasser. (Drawing of animal appeared above this statement.)
- Tandy and Jasser are the same kind of animal.
- One day, Tandy had a baby. That means that the baby came out of Tandy's tummy.
- But Tandy could not take care of the baby. So, right after the baby was born, it went to live with Jasser.
- Tandy never saw the baby again. Jasser took care of the baby.
- The baby grew up with Jasser and now it is 6 years old.
- Look—Tandy has pointy ears. And guess what—on this planet, animals with pointy ears eat berries.
- Look—Jasser has floppy ears. And guess what—on this planet, animals with floppy ears eat grass.

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