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The Nature and Variability of Children's Alternative Conceptions of Evolution

by

Uyen Adelyn Ly

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Education

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

Committee in charge:

Professor Kathleen E. Metz, chair
Professor Andrea diSessa
Professor Tania Lombrozo

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The Nature and Variability of Children's Alternative Conceptions of Evolution

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Uyen Adelyn Ly

Abstract

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Doctor of Philosophy in Education

University of California, Berkeley

Professor Kathleen E. Metz, Chair

In recent years a large amount of research has focused on the alternative conceptions about evolution found among secondary and university students, but few studies have investigated younger students' ideas on this subject. The present study examines the alternative conceptions of evolution harbored by second and third-grade students who participated in a summer instructional course that scaffolded the mechanisms of natural selection through cases of microevolution. In order to identify the categories of alternative conceptions that students expressed, 60 sets of pre- and posttest structured interviews were analyzed, and these showed that participants in this study expressed alternative conceptions closely related to those identified in studies conducted using high school and college-age participants. The results demonstrated a variability of alternative conceptions across a range of interview items, and also revealed how contextual features in the assessment tasks may account for the patterns that emerged in students' responses. Students' evocations of alternative conceptions declined after their participation in the instructional course. The analyses of the four case study students, whose pre-and posttest patterns were representative of their cohorts, provided a detailed within-subject look at how these alternative conceptions occurred in the context of the interview items and how they changed from pre- to posttest. These findings have broad relevance to understanding conceptual development in young children and important implications both for considering at how early an age instruction about evolutionary biology should begin and for evaluating the potential long-term impact of a curriculum that targets sources of student difficulty at earlier grade levels.

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Chapter 1: Introduction

It is remarkable how often a person who is trying to solve a particular evolutionary problem goes through the same sequence of unsuccessful attempts to find the solution, as has the whole field of evolutionary biology in its long history.

Ernst Mayr

The babies of these [cheetahs], their legs would probably grow longer so they can adapt to catch the gazelle. After generations it would be well-adapted to do something where it lives
If something is adapted to run after something, it's built to run fast.

A third-grade student explaining why cheetahs today are faster than their ancestors

One of the ironies of modern science is that evolution, which provides the framework for all biological thought, is often fundamentally misunderstood, even by students who accept it as true (Bishop & Anderson, 1990; Sinatra, Southerland, McConaughy, & Demates, 2003; Shtulman, 2006). Studies in conceptual change research for the past thirty years have shown that students come into the classroom with a set of already developed intuitive ideas about natural phenomena, ideas that are drawn from their day-to-day experiences navigating through the world. From a constructivist perspective, students interpret new information in the light of these existing ideas, which then become modified or supplanted. One of the key findings of this research in the field of evolution education is that students' intuitive ideas often run counter to ideas formally taught in science courses. These alternative conceptions have been observed in the answers to and explanations of adaptive evolutionary questions made by adolescents and adults.

Misconceptions about evolution commonly held by high school and college students have been linked to certain cognitive biases identified in young children, such as essentialism, anthropomorphism, and teleology (Carey, 1985; Inagaki & Hatano, 2002; Keil, 1992; Kelemen, 1999; Wellman & Gelman, 1992). What that link is, how these misconceptions develop and how they can be modified through instruction are subjects of research that still remains limited. Apart from several studies of young children's creationist ideas about the origins of species (Berti, Toneatti, & Rosati, 2010; Evans, 2000; Samarapungavan & Weirs, 1997), there is little research in the field of evolution education at the elementary school level. In particular, what young children believe about the mechanism of natural selection remains, to a great extent, unknown.

The purpose of this study is to examine the preconceptions that second- and third-grade students have about adaptive evolutionary phenomena, to explore in what ways these preconceptions are related to those held by students later in life, and to determine what impact a novel instructional intervention has on these inchoate beliefs. Until now there have been no systematic studies directly examining the variability of early elementary student ideas across a range of contexts, or phenomenal task settings. This study looks at variability both at a single point in time (from task to task within one interview) and at two points in time (in interviews before and after an instructional course). The final phase of the study assesses how young children's alternative conceptions change or persist after they have participated in an instructional course designed to scaffold the underpinnings of natural selection. It also seeks to establish the role of context in revealing or obscuring students' conceptual development. This research can potentially illuminate both the effect of instruction on the changes in young children's reasoning about evolution and the effect of context on their explanations about evolution.

Research Perspectives

Cognitive biases and naïve ideas in biology. A review of evidence from the developmental psychology suggests that some resistance to understanding natural selection may stem from powerful "rules of thumb" that shape our thinking (Wellman & Gelman, 1998). These rules, which are characterized as "cognitive biases" (Keil, 1993) and predispositions (Gelman & Wellman, 1991), hold a contradictory role in science learning. They can be said both actively to guide reasoning about living things and to impede the understanding of evolution. Divided into three broad categories, they are the essentialist bias, the teleological bias, and the anthropomorphic bias.

The essentialist bias. Psychological essentialism is the heuristic to draw a non-arbitrary relationship between the represented deep properties and the represented surface properties in concepts (Medin & Ortony, 1989). In terms of biological concepts, an essentialist constraint would lead one to believe that the salient, observable properties of an organism are determined by underlying non-observable properties at its core, its "essence." According to the evolutionary theorist Ernst Mayr (1988), essentialism was a world view founded by the Pythagoreans and Plato that taught that all seemingly variable phenomena of nature could be sorted into classes. Each class is characterized by its definition, or its essence.

This commonplace assumption that an organism's species kind is a reliable predictor of its properties is adequate for everyday reasoning about the biological world. Knowing that an organism is a duck, for example, allows us to make accurate predictions about how that organism should look (like a bird with webbed feet), where the organism should live (on water), how the organism should reproduce (by laying eggs), and so forth. However, despite its utility for reasoning about the properties of individual organisms, essentialism has proven a hindrance for reasoning about population-level phenomena, such as evolution and natural selection. As Shtulman (2011, p. 3) aptly notes, the "problem is that biological essentialism, while true in sprit, is false in detail." Offspring resemble their parents, but the resemblance is not identical. Our essentialist tendencies lead us to overlook the fact that all individual organisms are unique and that variation exists in every population.

The essentialist tendency has been observed in children as young as two years old (Gelman & Coley, 1990; Gelman & Markman, 1986). Gelman (2003) suggests that individuals of all ages assume that the outward appearance and behavior of a species are determined by a kind of hidden causal power or "essence." Children also believe that species' members possess an innate potential to develop the same traits (Gelman & Welman, 1991).

According to Gould (1996) and Mayr (2001), the essentialist focus on similarities among members of the same species rather than their differences led pre-Darwinian theorists to deem within-species variation inconsequential or unimportant, obscuring the fact that not all members of a population will survive long enough to reproduce. Mayr (2001) characterized the pre-Darwinian theories that construed evolution as the cross-generational transformation of a species' underlying essence as "transformational" theories of evolution. This theory purports that every organism will produce offspring that are more adapted to the environment than it was itself at birth.

Shtulman's work (2006) has revealed that many college students are transformationists. When asked to reason about microevolutionary phenomena (i.e., variation, inheritance, and adaptation) or macroevolutionary phenomena (i.e., domestication, speciation, and extinction), many students appeal to the gradual transformation of an entire population (e.g., "The cheetahs became faster over time.") rather than the selective survival and reproduction of particular individuals within that population (e.g., "Faster cheetahs were more likely to reproduce than the slower ones."). It has also been found that adults who held essentialist beliefs-denying within-species variation-were significantly less likely to demonstrate a selection-based understanding of evolution than adults who accepted within-species variation (Shtulman & Schulz, 2008).

Mayr (2001) identified Lamarckianism as another theory based on essentialism. According to this theory, evolution is caused by the gradual change of organisms owing either to "use or disuse" of a structure or other trait or to the direct influence of the environment on the species' trait. This theory assumes that the genetic material is "soft," that it can be molded by environmental influences, and that these changes can then be transmitted to future generations by an "inheritance of acquired characteristics." Many research studies have found the "soft inheritance" of Lamarckian evolution to be a common alternative conception among high school and college students (Bishop & Anderson, 1990; Brumby, 1979; Bizzo, 1994; Deadman & Kelly, 1978; Demastes, Good, & Peebles, 1996; Ferrari & Chi. 1998; Greene, 1990; Kampourakis & Zogza, 2008; Jimenez-Aleixandre & Fernandez-Perez, 1987; Nehm & Reilly, 2007; Nehm & Schonfeld, 2007; Settlage, 1994).

The teleological bias. Teleology, a term attributed to Aristotle, is the attribution of function and purpose to nature and to human creations. The teleological tendency to assume that objects exist for a purpose has also been found to play a role in children's emerging naïve conceptions of the biological world (Kelemen, 1999). Researchers theorize that the teleological bias derives from children's privileged understanding of intentional behavior and artifacts. Children are prone to what Kelemen (1999, p. 244) calls "promiscuous teleology" in which artifacts and natural objects of all types are viewed as existing to complete a function (Kelemen, Widdowson, Posner, Brown, & Casler, 2003). Four year olds in Kelemen's study (1999) insist that everything has a purpose, including things like lions ("to go in the zoo"), clouds ("for raining"), and pointy rocks ("for animals to scratch on them when they get itchy"). Kelemen and Rosset's more recent study (2009) demonstrates that even adults have a "human function compunction" in that they too have a bias towards teleological explanations of natural phenomena. The results of her experiments indicate that teleological explanations are maintained as an interpretive default throughout development, even among college students who have taken several courses in science. Lombrozo, Kelemen and Zaitchik (2007) have also found that patients with Alzheimer's disease, or sparse background beliefs, systematically prefer teleological explanations. Their findings suggest that an underlying tendency to explain objects and phenomena in terms of function persists throughout life.

The literature in evolution education reveals a prominence of teleological reasoning among students in high school and college (Bishop & Anderson, 1990; Demastes, Good, & Peebles, 1996; Tamir, 1985). Tamir and Zohar's study (1991) found that 71% of the tenth graders and 56% of the twelfth graders in their research employed teleological reasoning when giving explanations of evolutionary change. Southerland, Abrams, Cummins, and Anzelmo (2001) also reports that across second-, fifth-, eighth-, and 12th-grade participants in their study, the most prominent type of response employed in students' explanations of biological phenomena was the teleological reasoning pattern in which the ends of the situation are used as a causal agent in determining the means.

The anthropomorphic bias. Anthropomorphism is the tendency to attribute human traits, such as intentionality, to non-human organisms and objects. The classic demonstration is that of Heider and Simmel (1944), who made an animated film that consisted of simple shapes—squares, triangles and circles—moving in systematic patterns that were based on psychological intuitions. When they asked observers to describe what they saw in the film, most observers developed elaborate stories about the circle and triangle being in love, or about the big gray triangle trying to steal the circle away from the other triangle. Guthrie's experiments (1993) also revealed that people attribute human characteristics to a wide range of entities, from automobiles and clothes to insects and wind. The capacity to attribute intentionality to minimal cues can even be observed in six-month-old infants (Leslie, 1982). Through a series of experiments manipulating the perceived unpredictability of a nonhuman agent, Waytz, Morewedge, Epley, Monteleone, Gao, and Cacciopo (2010) found that one determinant of anthropomorphism is the motivation to be an effective social agent that entails maintaining a sense of predictability, control and understanding over one's environment.

Carey (1985) claimed that children before age 10 make predictions and explanations for biological phenomena based on intuitive psychology (i.e., intentional causality). According to her, children lack the mind-body distinction and thus do not recognize that our bodily functions are independent of our intentions and that biological processes that produce growth or death are autonomous. Inagaki and Hatano (1987) argue that children as early as age six have acquired a form of biology that is "psychological" in nature but autonomous from psychology. They reason that when children do not have enough knowledge about an animate object, they can make an educated guess by using personification or the person analogy in a constrained way. Their proposed framework, vitalistic biology, sheds positive light on the Piagetian idea of childhood animism and egocentrism. According to them, children have the ability to make inferences about bodily processes, as well as about animals' and plants' properties and behaviors, based on personification. However, the results in their lab studies suggest that young children do overattribute human mental properties to bodily organs (Inagaki & Hatano, 2002) as well as to plants, animals and inanimate objects (Inagaki & Sugiyama, 1988).

Conceptual difficulty of evolution. Empirical studies investigating students' conceptions of evolution report a limited ability to interpret and solve problems in Darwinian terms, even after years of instruction in biology (Bishop & Anderson, 1990; Demastes et al., 1996; Demastes, Settlage, & Good, 1995; Jensen & Finley, 1996; Settlage, 1994; Shtulman, 2006). These studies are part of a growing body of research suggesting that persistent barriers to understanding natural selection arise "not [from] what the student lacks, but [from] what the student has, namely alternative conceptual frameworks for understanding the phenomena covered by the theories we are trying to teach" (Carey, 2000, p. 14). These alternative conceptions are abundant and include explanations based upon essentialism, anthropomorphism, teleology, and Lamarckian evolution (Bishop & Anderson, 1990; Brumby, 1984; Clough & Wood-Robinson, 1985, Demastes et al., 1996; Evans, 2008; Shtulman, 2006; Settlage, 1994). Some researchers have established claims about the link between these common alternative conceptions that adults have and the cognitive biases in biology that have been documented in preschool children (Evans, 2008; Sinatra, Brem & Evans, 2008). They suggest that in order to understand the advanced scientific concepts underpinning the Darwinian theory of evolution, students cannot rely on simply memorizing facts. They must learn how to restructure their naïve, intuitive ideas about the natural world into views consistent with Darwinian principles. In other words, they must undergo conceptual change.

Conceptual change. To understand why the theory of evolution is commonly misconceived, we must recognize that not all knowledge comes easily. Certain subjects, particularly those in the field of science (e.g., physics, chemistry, biology), are persistently more difficult to learn and accordingly more difficult to teach. Education research in the past thirty years has reconciled this problem with a learning theory that recognizes that not all learning is cumulative and domain-general, and that concepts change through the enrichment of prior knowledge. This perspective to understanding difficult science learning that includes among its components knowledge restructuring is called conceptual change.

Conceptual change is an approach that rests on an assumption that students enter the classroom with intuitive and naïve ideas about how the world works. There is a divide between those researchers who consider the structure of students' intuitive ideas to be misconceptions that are relatively coherent across contexts and present obstacles to the acceptance of normative views (Chi, 1992; Carey, 1999; Gopnik & Meltzoff, 1997; Vosniadou, 1994) and those who consider instead the productive or constructive role of students' fragmented, context-sensitive, intuitive ideas in the acquisition of expertise (diSessa, 1988; Hunt & Minstrell, 1994; Smith, diSessa, & Roschelle, 1993; Hammer, 2000; Linn, 2008). Thus, the processes of conceptual change or reorganization of conceptual knowledge may be approached in different ways. Those who believe misconceptions to be coherent (Chi, 1992; Carey, 19999; Gopnik & Meltzoff, 1997; Vosnaidou, 1994) describe conceptual change as a process of reorganization, revision, or shifting across coherent models, theories, or ontological categories. In the fragmented, constructivist view, conceptual change is best viewed as a process of integration (Linn, 2008) or coordination (diSessa, 2004). The "knowledge in pieces" view contends that concepts change through a cognitive process involving a collection of elements that are connected and applied to a problem depending on the contexts and nature of the problem.

Research on elementary students' beliefs about evolution. Most studies in evolution education have looked at students' naive ideas at the high school and college grade level. Our knowledge of elementary students' ideas about evolution remains limited. There are a few studies that have looked at elementary students' beliefs about the origins of species. Evans' study (2000) demonstrated a developmental pattern in children's explanations for biological origins. There were age-related shifts from mixed creationist and spontaneous generationist explanations, to an exclusive creationism, and finally to Lamarckian or creationist explanations. Samarapungavan and Weirs (1997) reported in their findings that nine-year-olds and 12-year-olds explain the phenomena of speciation in essentialist terms.

There are no studies that directly examine how elementary school children think about the mechanism of adaptation. The studies with adolescents and adults (listed above) show that while they do have some understanding of adaptational pressure, many students fail to understand the mechanisms underlying evolutionary change. This study expands the research on naïve ideas about evolution in an overlooked age group, the early elementary years, by examining the nature of second- and third-grade students' ideas about the mechanism of evolution. Moreover, this research explores the potential mutability of their ideas as it traces the changes in students' alternative conceptions after their participation in an instructional course that was developed to scaffold the conceptual underpinnings of natural selection though cases of microevolution.

Moderate success of instruction on alternative conceptions about evolution. Evolution education studies have also shown how entrenched alternative conceptions to evolution can be, even after years of education in biology (Bishop & Anderson, 1990; Demastes et al., 1996; Demastes, Settlage, & Good, 1995; Jensen & Finely, 1996; Settlage, 1994). These research studies also document students' conceptions of evolution both before and after instruction and report a limited ability on the part of many to solve problems in Darwinian terms (Bishop & Anderson, 1990; Demastes, Good, & Peebles, 1995, Demastes et al.,1996; Demastes, Settlage, & Good, 1995a; Jensen, Odem, & Settlage, 1996; Jimenez-Aleixandre, 1992; Settlage, 1994).

A small number of studies have evaluated the effectiveness of teaching strategies in improving students' conceptions of evolution. Bishop and Anderson (1990) developed instructional materials (i.e., laboratory activities, problem sets, overhead transparencies, handouts) designed to help students recognize the inadequacy of their naïve conceptions and develop appropriate scientific conceptions in their place. Although their course instruction was moderately successful in improving students' understanding of the evolutionary process, they found that many students still harbored a number of alternative conceptions. Their study was replicated by Demastes, Good, and Peebles (1996), who also reported moderate success in supplanting students' alternative conceptions with normative ones. Jensen and Finley (1995) found the use of a history-based curriculum used in conjunction with small discussion groups to be also moderately effective at helping students overcome their misconceptions.

Item Feature Effects in Evolution Assessment. Emulating the instructional model, the larger research team has also developed an assessment instrument (see Appendix) that is comprised of multiple tasks grounded in cases of microevolutionary phenomena. The instrument also includes tasks that are non-microevolutionary and derived from the literature (Bishop & Anderson, 1990). The unique range of assessment items in this research will allow for an in-depth look at the effect of context, the phenomenal settings of the task, on students' explanations.

Although a large body of work in cognitive psychology has explored how assessment task features, formats, and contexts constrain and facilitate knowledge retrieval, mostly in the domain of physics (Chi, Feltovich, & Glaser, 1981; diSessa, Gillespie, & Esterly, 2004; Greeno, 2009), there have been only two known studies that have investigated these issues in the biological sciences (Clough & Driver, 1986; Nehm & Ha, 2010). Clough and Driver (1986) reported that across evolutionary prompts, there was a considerable consistency in the use of the accepted scientific framework, but little consistency in use of alternative frameworks. These findings contrast with those of Shtulman (2006), where a consistency was found in college students' use of transformationism, an alternative framework to natural selection. Nehm and Ha (2010, p. 2) asserted that "studies continue to be published that identify, but do not explicitly investigate, how evolution item features may be controlling knowledge and misconceptions measurements." In their study, they documented significant and predictable item feature effects on evolutionary explanations. In particular, tasks involving between-species comparisons, regardless of trait gain or loss, animal or plant, always produced significantly more naïve biological explanatory elements than within-species comparisons. They also found tasks involving evolutionary trait loss elicited a greater number of alternative conceptions than evolutionary trait gain in all contexts, including within-species comparisons, between-species comparisons, animal prompts, and plant prompts. The studies by Clough & Driver and Nehm & Ha both focused on college age students. No research—until now—has examined these issues in the education of young children.

The Current Project's Instructional Intervention

The larger project in which this study resides developed a curriculum that teaches the conceptual underpinnings of natural selection through cases of microevolution. This unique approach was created with the intent to mitigate alternative conceptions about evolution, in the belief that the small scale of the changes addressed would decrease the likelihood of attribution to external agents and that the relative transparency of variation in population would potentially lessen essentialist or transformational reasoning. Few curriculum studies have taken this approach to the teaching of evolution. The goal is that this type of instructional intervention will be effective in helping students avoid the pitfalls that lead them to invoke alternative conceptions about evolution. To that end, this dissertation illustrates through multiple case studies how participation in the project's instructional course appeared to help students supplant alternative conceptions with principles more consistently normative. The findings from these analyses could have important implications for considering how early instruction about evolutionary biology should begin and the potential long-term impact of a curriculum that targets the sources of student difficulty in earlier grade levels.

The current study also expands upon the limited research on context effects and explores whether patterns emerge across evolutionary reasoning contexts, and the implications of these patterns for assessment and models of cognition. It examines the combined effect of item features (i.e., dichotomous vs. continuous traits, looking forward vs. backwards in explaining change, and microevolutionary vs. non-microevolutionary phenomena) on student response. It investigates the role of context in revealing students' competence by highlighting to what extent the phenomenal settings of the assessment tasks reveal conceptual development by looking at how certain tasks lend themselves to invoking alternative conceptions while others in the same interview can prompt students to evoke their understanding of evolutionary principles learned from the instructional intervention. These findings could potentially inform the development of evolutionary assessment tasks. If the role of context may be shown to account for a pattern of student reasoning and is therefore taken into consideration, future assessment instruments could expand their ability to accurately and comprehensively assess students' reasoning about evolutionary phenomena.

Dissertation Objectives

This dissertation examines the alternative conceptions that second- and third grade students have about evolution. The study looks at the effects of a three-week instructional course on students' reasoning by tracing the changes in conceptions across the participants' pre- and post-instruction tests. This study also explores whether contextualization patterns emerge within particular evolutionary reasoning contexts.

Questions and Hypotheses Guiding This Study

What are the alternative conceptions that young children have about evolution? Certain cognitive biases, such as essentialism and teleology, are pervasive among preschoolers and adults. However, there is a gap in our understanding of early elementary students' reasoning on the process of evolution. This research explores early second- and third-grade students' intuitions about natural selection and aims to answer the following sub-questions: Are they similar to or different from the types of alternative conceptions commonly found in high school and college students' explanations about evolution? Are some alternative conceptions more common than others at this age?

I hypothesize that the second and third-grade participants in this study will express alternative conceptions that are similar to those of adults. I reason that their conceptions will relate to the cognitive biases (e.g., anthropomorphism, teleology, essentialism) that have been documented in the child psychology literature. It has been argued that these cognitive constraints are linked to the alternative conceptions that have been observed in adults' explanations about evolutionary phenomena (Evans, 2008; Sinatra et al., 2008).

How variable or consistent are children's alternative conceptions across the range of tasks in an interview? One of the most fundamental elements of an understanding of learning lies in the description of the structure of knowledge. Linder (1993) described the most prevalent model of learning currently applied in science education research as a theory-based perspective. Within this model, learners' conceptions are thought to be coherent and systematic. An alternative to the theory perspective of students' understanding, which is diSessa's "knowledge in pieces" model, will also be explored in this study. Employing this perspective, novice science learner's knowledge is understood to be not a tightly connected, logically organized structure, but a set of loosely connected ideas about the world that can be used to generate explanations in particular situations and in response to particular questions or cues. This study explores these two differing perspectives as possible ways of viewing the nature of students' biological knowledge structures.

My hypothesis is that students' responses in this study will not reveal a naïve coherent conceptual framework. I predict that the young participants' explanations will most likely be variable within and across the participants as they generate their explanations spontaneously according to the relevance to the situation of the questions in their pretests. This hypothesis is based on the assumption that most second and third-grade students do not have content knowledge in the domain of evolutionary biology. We may therefore expect their weak knowledge systems to be reflected in their on-the-spot answers to the questions in the pretest. The predicted ad hocness and piecemeal nature of their explanations will more likely be supported by the knowledge in pieces perspective, based on its emerging recognition of the situated nature of student learning and the recognition of the possibility of a myriad of learning pathways (diSessa, 1993; Hammer, 1996; Smith, diSessa, & Roschelle, 1993).

To what extent can context account for the patterns that emerge in students' explanations across contexts? Despite the well-established findings from science education research communities that assessment features significantly control knowledge elicitation in many domains—particularly chemistry and physics—very few empirical studies have investigated these issues in the biological sciences (Clough & Driver, 1986; Nehm & Ha, 2010). This study explores whether contextualization patterns emerge across evolutionary reasoning contexts, and the implications of these patterns for assessment and models of cognition.

My hypothesis predicts that the features of the assessment tasks will play a critical role in accounting for the variability in students' explanations across the range of those tasks. The evidence from the large body of work in cognitive psychology that has explored how assessment task features, formats, and contexts constrain and facilitate knowledge retrieval supports this prediction (Chi, Feltovich, & Glaser, 1981; diSessa, Gillespie, & Esterly, 2004; Greeno, 2009). Domain-specific studies in science education have likewise explored how assessment tasks differentially reveal the composition and coherence of student knowledge and alternative conceptions (Clough & Driver, 1986; Jones, Carter, & Rau, 2000; Ozdemir & Clark, 2009; Palmer, 1999).

How do young children's alternative conceptions change or persist after their participation in an instructional course that scaffolds the conceptual underpinnings of evolution? Evolution education research has shown the persistence of alternative conceptions in students' reasoning among those who have taken one or more biology courses in high school and/or college. A number of studies (Bishop & Anderson, 1990; Demastes et al., 1996; Jensen & Finley, 1995) that have focused on the effectiveness of teaching strategies have revealed moderate success in supplanting students' alternative conceptions with normative ones. This study investigates whether participants' exposure to an instructional course based on a learning-progression perspective can make a difference in the frequency of alternative conceptions that are invoked in students' explanations. The course, which was collaboratively developed by a research team, scaffolds the conceptual underpinnings of natural selection through cases of microevolution. The analysis of this study assesses how robust or malleable students' alternative conceptions are. Also investigated are the certain types of conceptions that are either more or less resistant to displacement by normative ideas.

My hypothesis is that the approach of the instructional course, which is the scaffolding of the mechanism of natural selection through microevolutionary cases, will help mitigate students' tendency to rely upon alternative conceptions. This approach will represent evolutionary phenomena within a single population and on a smaller time scale. At this small scale, the idea of within-kind variation will be relatively transparent to the students. It has been found that drawing students' attention to within-kind variation is highly effective in replacing transformational conceptions with variational ideas (Shtulman & Calabi, 2008).

Research Objectives

To answer these questions and test these hypotheses, I examine the alternative conceptions that were expressed by second- and third-grade participants across 60 sets of pre-and posttest interviews. I investigate the changes that occur in students' alternative explanations following their participation in the instructional intervention. To help explain the changes that occur across this spectrum of students, my analysis also focuses on the contexts in which these alternative conceptions are invoked by demarking the assessment items according to their constituent features and examining explanations that were generated within each context. Four case studies are developed to provide a more comprehensive account of change and to offer a lens on the ways students' alternative conceptions persist or change under different features of the tasks.

The final section of this study attempts to identify significant patterns in the movement from pre- to posttest understanding and to assess what those patterns reveal about the resiliency of alternative conceptions. I am particularly interested in the contexts that facilitate normative displacement of alternative conceptions and those which promote their endurance. Along the way I will highlight elements in the research findings that offer potential insight into assessment effectiveness and point to fruitful areas for continuing study.

Chapter 2: Methods

Dissertation Overview: Outline of Two Analytic Strands

The purpose of this study is to describe and explore the alternative conceptions that second- and third-grade students have about evolution. The analysis proceeds in two inter-related strands to answer the following questions.

1. What are the alternative conceptions that young children have about evolution?
2. How variable or consistent are children's alternative conceptions across the range of tasks in an interview?
3. To what extent do the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in students' explanations across contexts?
4. How do young children's alternative conceptions change or persist after their participation in an instructional course that scaffolds the conceptual underpinnings of evolution?

The first strand of analysis explores on a group level the types of alternative conceptions that second- and third-grade students have about evolution. This analysis also maps the changes in students' ideas across 60 sets of pre-and posttest interviews. The findings of these analyses will be covered in Chapter 3.

The second strand of analysis explores the patterns that emerge from the first strand in four case studies. These in-depth analyses focus on students whose set of conceptions are representative of the patterns that emerged on the cohort level. Chapters 4 through 7 will be devoted to each of the four individual case studies.

Context of the Study: the Larger Research Project

The current analysis takes place within a large-scale study entitled *Development of the Conceptual Underpinnings of Evolution in Second and Third Graders.* This study was a project of University of California, Berkeley, funded by the National Science Foundation (NSF 081-8421 TPC), and directed by Kathleen Metz.

The study was designed to apply the learning progression perspective to the teaching of evolution. The goal of the study was to establish the initial steps of a learning progression with the object of creating a strategic early intervention in the primary grades that would have an advantageous impact on long-term student understanding of evolution. The design of the learning progression had a three-fold aim of leveraging children's intellectual resources to: 1) build an understanding of evolution, 2) mitigate common alternative conceptions, and 3) strategically position children to understand more fully the theory of natural selection at subsequent grade levels.

The study involved the development of a learning progression supported by two curriculum modules. The progression and modules were framed to build explanatory power about the fit between organisms and their environments. An assessment instrument was also developed to measure students' understanding of the concepts underpinning natural selection as they emerged in their explanations about evolutionary phenomena. Through multiple sources of data, the research team closely examined children's conceptual development under the conditions of the project's instructional model, as enacted in both laboratory and public school classroom settings.

The research design of the larger project consisted of four cycles of research. There were two cycles of a 14-half-day project-run summer instructional program. Separate from the summer program, there were two semesters of classes with three to four second- and third-grade teachers enacting the curriculum modules in a public school. In the summer program setting, the research team had complete control over student assignments and instruction. Both sites were situated in inner city classrooms, serving ethnically and economically diverse student populations.

This dissertation focuses on the alternative conceptions that were evoked in the explanations that students gave in their pre- and posttest interviews for the two cycles of the summer instructional program.

Participants. Forty seven second- and third-grade students participated in the instructional course and the 60 sets of pre- and posttest interviews that made up this study. Of the 34 second and third-grade students who enrolled in the summer enrichment program in year one and 37 in year two, 29 students from year one and 31 students from year two fulfilled the selection criteria for participants in this study. The participants who were selected completed the summer program (participated in at least 10 days of instruction) and took part in both videotaped pre- and posttest interviews. Of the 47 second- and third-grade students who participated in this study, 29 participated in year one of the study and 31 participated in year two. Thirteen of the 29 students from year one returned to participate in year two of the study. The students in each class for each year were balanced in grade level, with roughly half in second grade and the other half in third grade. In year one of the study, students were randomly assigned to one of two classes, 15 students in the Animals and their Behavior (AB) class and 14 in Botany. In year two, the returning students participated in that class to which they were not exposed in the prior year. The study took place at an urban public elementary school located in the Bay Area in Northern California.

Table 1.
Gender Breakdown of Participants in Class and Cohort

	Male	**Female**
Animals 2009	60%	40%
Botany 2009	54%	46%
Animals 2010	53%	47%
Botany 2010	59%	41%

Table 2.
Ethnic Breakdown of Participants in Class and Cohort

	African-American	**Asian-American**	**Anglo-American**	**Latino-American**
Animals 2009	46%	20%	20%	14%
Botany 2009	38%	23%	16%	23%
Animals 2010	42%	21%	21%	16%
Botany 2010	35%	29%	24%	12%

Data Sources. My research relies mainly on the analysis of students' videotaped pre- and posttest interviews. Two sets of data points inform my analyses. The first set includes the pre- and posttests of the 29 students who participated in year one of the study. The second set consists of the tests of the 31 students who participated in year two.

Scope. The analyses of this study were bound in time over the span of two summers. In each year of the study, the students participated in a summer instructional course conducted over 14 days (three weeks). Each class day was three hours long, yielding a total of 48 hours of class time. The summer program was comprised of three discrete parts. In the first, researchers conducted interviews with students to determine their entering levels of understanding. The second part was the three-week instructional intervention, in which members from the research team taught the course, implementing the curriculum material designed to scaffold the conceptual underpinnings of natural selection. Part three repeated the interviews of part one to assess the impact of the instructional intervention on students' understanding.

The Learning Progression and Instructional Intervention. Because this study traces the changes in students' ideas after their exposure to the instructional intervention, this section will describe in brief the purpose and design of the learning progression and curriculum modules.

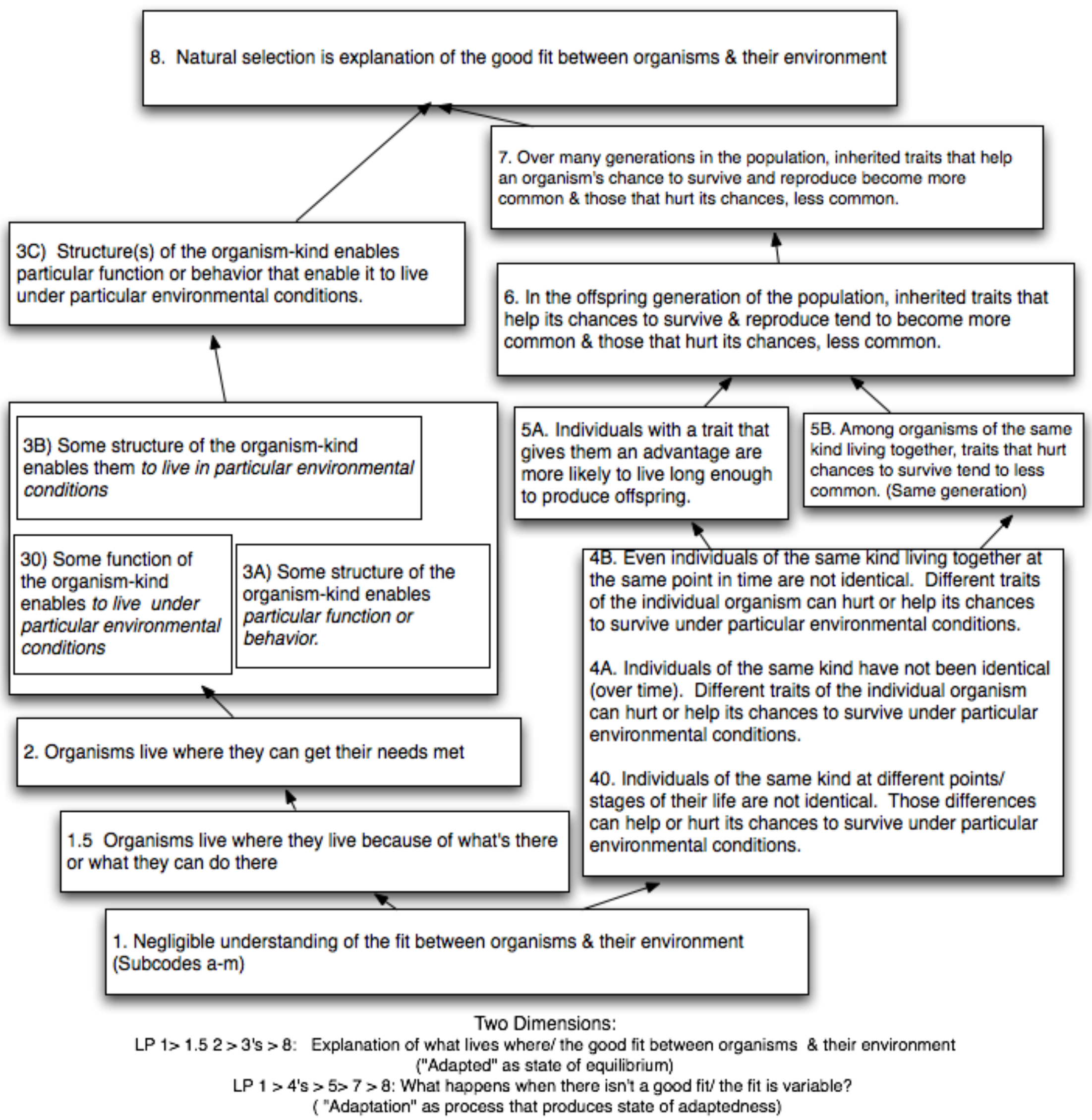
According to the NRC report, *Taking science to school: Learning and teaching science in grades K-8* (2007), a learning progression is a description of the successively more sophisticated ways of thinking about a topic that can follow and build on one another as children learn about and investigate a topic over a broad span of time (e.g., six to eight years). Its approach has four characteristics: (1) making use of current research base, (2) organizing conceptual knowledge around core ideas, (3) recognizing multiple sequences and web-like growth, and (4) interconnecting strands of scientific proficiency. The four strands of scientific proficiency, according to the NRC, include the following: (1) know, use, and interpret scientific explanations of the natural world, (2) generate and evaluate scientific evidence and explanations, (3) understand the nature and development of scientific knowledge, and (4) participate productively in scientific practices and discourse.

The central idea in this project's learning progression is to build increasingly powerful explanations about the variation of organisms and environments and the fit between the two (see Figure 1). To that end, the instruction addresses concepts fundamental to an understanding of the mechanism of natural selection. Among these basic, preliminary concepts are the structure and function of biological traits, trait variation in organisms (both between and within kind), the survival and reproductive advantage of traits, limiting factors in the environment, and the broad concept of change over time. By establishing these conceptual footings, the course seeks to give children the foundation necessary to develop an understanding of natural selection, a foundation that will support increasingly sophisticated (and enduring) comprehension at higher grade levels. The learning progression designed for this study was crafted into two curriculum modules, each examining the same concepts as they apply to plants and animals and their behavior. Approximately one third of the students at both sites participated in both modules over a two-year span, revisiting the same conceptual terrain in the second domain.

The learning progression is framed at the system level of microevolution, or evolution on a small scale—within a single population. The cases of microevolution are drawn from the research literature. These cases make salient and accessible to young children the ideas of variation and environmental changes. They are structured in the form of thought experiments to engage children in applying conceptual ideas in generating predictions and explanations, and also in comparing predictions to empirical outcomes (as derived from the research literature).

The thought experiments also promote students' theory-building, based on concepts that are scaffolded, such as the transition from the idea of differential survival value of traits to the idea of changes in relative frequency over time.

Figure 1.
Model of the Learning Progression



Pre- and Posttest Interviews with Each Student. The pre- and posttest exercises are one-on-one-structured interviews with standardized probes encouraging elaboration. The tasks in these interviews are based on real-world cases of evolution and employ photographs, and/or realistic icons and templates for students to manipulate. With the exception of one task, all of the interview tasks require transfer of ideas taught in the curriculum to new contexts and organisms that are not taught in the curriculum.

The tasks can take the form of predicting and explaining what a population will look like after an environmental change, explaining the fit between organisms and their environment, or explaining the change of an organism-kind today in contrast with its ancestors. I have chosen to capitalize on this assessment instrument for purposes complementary to those of the research team. Whereas the research team assesses student learning gains along the levels in the learning progression, I analyze the students' pre- and posttest explanations to investigate their intuitive and naïve ideas about evolution and the changes thereto.

Procedure. Each interview took place on site at the student's elementary school with an interviewer and one student seated at a table. A videotape camera mounted in front of the student captured the interaction between interviewer and participant as well as templates and icons the students manipulated to illustrate their responses to several of the questions. While the interviews, which varied in length from 30 minutes to an hour, took place at different times of day, the interviews themselves were uniformly structured and the questions formulated according to systematic guidelines. Each participant was exposed to the same assessment items in both the pre- and posttest phases.

The Interview Guidelines. At the beginning of each session, the interviewer provided a brief overview of the research and described how the study would be conducted.

1. The interviewer explained that she was part of a team doing research on how to teach science and how to help kids learn about science.
2. She further explained that a video camera and audio recorder would record the interview because other people in the research team were really interested in the student's ideas.
3. The interviewer asked if the student wanted to stay and participate in the interview.
4. Once the student gave consent, the interviewer stated that the exercise could be stopped at any time and the student could return to class whenever he or she wished.

Materials. Participants' reasoning about evolution was assessed with a multi-question structured interview, reproduced in Appendix A. Year one of the study assessed participants' evolutionary reasoning on the basis of a five-task interview. A sixth task originally included in the interview was eliminated from analysis of this study due to its consistent misinterpretation by many of the students. Year two of the study assessed participants' evolutionary reasoning on the basis of a seven-task interview. The set of interview assessment tasks administered in year one and year two were not identical. See Tables 3 and 4 for the set of assessment items administered for each year.

The assessment tasks within each interview varied both in the nature of the tasks and in the configuration of features designed to drive the discussion. Among these features were dynamic assessment scaffolds, empirical feedback drawn from the literature (i.e. "what the scientist actually saw"), and use of manipulable icons and templates (used by students to explain their predictions of generational change). See Tables 3 and 4 for the set of design features in each assessment task for years one and two respectively.

Table 3.
Nature of the Task and Features of the Set of Assessment Items in Year One

Assessment Item	Nature of the Task	Features of the Task
Sea Otter and Kelp	To explain "why do sea otters live where they live" and "why does kelp live where it lives"	-No added features
Kauai Cricket or *Brassica rapa*	To predict and explain the second and seventh generation of crickets/*Brassica rapa* after the arrival of an environmental press	-Students display their prediction employing a template and icons
Peppered Moth	To predict and explain the 20th generation of peppered moths after the arrival of an environmental press	-Students display their prediction employing a template and icons
Endler's Guppy	To predict and explain the second and fifth generation of guppies after the arrival of an environmental press To explain the empirical feedback	-Students display their prediction employing a template and icons -Empirical Feedback
Cheetah	To explain how cheetahs today can run so much faster than their ancestors	-Dynamic assessment

Table 4.
Nature of the Task and Features of the Set of Assessment Items in Year Two

Assessment Item	Nature of the Task	Features of the Task
Rainforest vs. Desert Plants	To explain why desert plants can or cannot survive in the rainforest and vice versa To explain how come desert plants can survive in the desert where there is so little water	-No added features
Kauai Cricket or *Brassica rapa*	To predict and explain the second and seventh generation of crickets/*Brassica rapa* after the arrival of an environmental press	-Students display their prediction employing a template and icons
Endler's Guppy	To predict and explain the second and fifth generation of guppies after the arrival of an environmental press To explain the empirical feedback	-Students display their prediction employing a template and icons -Empirical Feedback
Banded Peacock Butterfly	To predict and explain the 50th generation of Banded Peacock butterflies after the arrival of the environmental press	-Dynamic Assessment
House Sparrows	To explain how House Sparrows in cold climates today are so much bigger than those from 100 years ago	-Dynamic Assessment
Cheetahs	To explain how cheetahs today can run so much faster than their ancestors.	-No added features
Fitness of Plants	To explain how plants have come to fit so well where they live	-No added features

First Strand of Analysis

Because each assessment task had its own unique configuration of design features (e.g., empirical feedback, dynamic assessment, etc.), I delineate each task into its constitutive components, where a task may have two to four components or episodes. Thus, the five assessment tasks in year one were further delineated into 19 episodes demarcated by the features of each item (see Table 5). The seven assessment tasks in year two were delineated into 18 episodes (see Table 6).

Table 5.

Delineated Episodes from each Assessment Item in Year One

Episode	Assessment Item	Nature of the Task
1	Sea Otter and Kelp	Explanation: Why do think sea otters live there?
2	Sea Otter and Kelp	Explanation: Why do think kelp lives there?
3	Cricket or *Brassica rapa*	Prediction and explanation: What do you think the crickets or *Brassica rapa* will look like one generation later, after the arrival of the flies or caterpillars?
4	Moth	Prediction and explanation: What do you think the moths will look like 20 generations later, after the arrival of the factories?
5	Moth	Explanation after empirical feedback, “what the scientist saw:” How is this different from one generation earlier? How did that happen?
6	Moth	Explanation after dynamic assessment for survival advantage of dark-colored wing trait
7	Moth	Explanation after dynamic assessment for survival and reproductive advantage of dark-colored wing trait
8	Moth	Explanation after dynamic assessment for survival and reproductive advantage of dark-colored wing trait, inheritance, and shift in distribution of traits
9	Moth	Explanation (returning to the original question): How did the moths’ color change?
10	Moth	Revoicing “what another student said” and evaluation of explanation
11	Guppy	Prediction and explanation: What do you think the guppies will look like one generation later, after the arrival of the predator fish?
12	Guppy	Explanation after empirical feedback, “what the scientist saw:” How is this different from one generation earlier? How did that happen?
13	Guppy	Prediction and Explanation: What do you think the guppies will look like another three generations later, after the arrival of the predator fish?
14	Cheetah	Explanation: How come cheetahs today are able to run so much faster than their ancestors?
15	Cheetah	Explanation after dynamic assessment for survival advantage of running fast trait
16	Cheetah	Explanation after dynamic assessment for survival and reproductive advantage of running fast trait
17	Cheetah	Explanation after dynamic assessment for survival and reproductive advantage of running fast trait, inheritance, and shift in distribution of traits
18	Cheetah	Explanation (returning to the original question): How come cheetahs today are able to run so much faster than their ancestors?
19	Cheetah	Revoicing “what another student said” and evaluation of explanation

Table 6.
Delineated Episodes from each Assessment Item in Year Two

Episode	Assessment Item	Nature of the Task
1	Rainforest and Desert Plants	Explanation: Do you think the plants that live in the rainforest can survive in the desert? Why or why not?
2	Rainforest and Desert Plants	Explanation: Do you think the plants that live in the desert can survive in the rainforest? Why or why not?
3	Rainforest and Desert Plants	Explanation: How come the plants in the desert can survive when there is so little water?
4	Cricket or *Brassica rapa*	Prediction and explanation: What do you think the crickets/*Brassica rapa* will look like one generation later, after the arrival of the flies/caterpillars?
5	Cricket or *Brassica rapa*	Prediction and explanation: What do you think the crickets/*Brassica rapa* will look like another five generations later, after the arrival of the flies/caterpillars?
6	Guppy	Prediction and explanation: What do you think the guppies will look like one generation later, after the arrival of the predator fish?
7	Guppy	Explanation after empirical feedback, "what the scientist saw": How is this different from one generation earlier? How did that happen?
8	Guppy	Prediction and explanation: What do you think the guppies will look like another three generations later, after the arrival of the predator fish?
9	Butterfly	Prediction and explanation: Does one of these pictures show what you think the butterflies will look like 50 years later, after the arrival of the birds?
10	Butterfly	Explanation after dynamic assessment of survival advantage of black-wing trait
11	Butterfly	Explanation after dynamic assessment of inheritance, survival and reproductive advantage of black-wing trait
12	Butterfly	Revoicing "what another student said" and evaluation of explanation
13	Sparrow	Explanation: How come sparrows that live in cold climates today are so much bigger than those from a hundred years ago
14	Sparrow	Explanation after dynamic assessment of survival advantage of large body trait
15	Sparrow	Explanation after dynamic assessment of survival advantage of large body trait
16	Sparrow	Revoicing "what another student said" and evaluation of explanation
17	Cheetah	Explanation: How come cheetahs today are able to run so much faster than their ancestors?
18	Desert Plants	Explanation: How come most plants fit so well where they live?

Pattern-coding and alternative conceptions category development. My initial stage of analysis involved watching all of year-one students' pre- and posttest interviews and noting their explanations within these episodes. I noted all students' explanations that were non-normative and alternative to the concepts that were taught in the curriculum. I identified and clustered alternative conceptions that were similar in type, keeping in mind that categories may emerge that are consistent with those from the evolution-education literature as well those that may fall outside of the literature. I identified the alternative conception categories on the basis of evidence for the alternative explanations being invoked more than once across students in their interviews. Any alternative explanation that was not expressed more than once across students was considered idiosyncratic and did not become its own category. The set of six alternative conceptions categories were then defined, operationalized, and used to identify their presence in each of the student's interviews. The second stage of analysis involved coding and analyzing 60 sets of pre- and posttest interviews (120 individual interviews) from both years of the summer program. A second coder was trained to code independently 30 randomly assigned individual interviews. Between the two coders, there was an 84% coding agreement across the episodes eliciting a type of alternative conception. In cases of disagreement, all coding discrepancies were resolved via deliberation.

Students' Alternative Conceptions. The following categories of alternative conceptions were developed emically from the data corpus: teleological, anthropomorphic, transformational, external agency, cyclical and Lamarckian. With the exception of "cyclical" explanations, all of the categories in Table 7 relate to alternative conceptions commonly found in the evolution education literature. A coding matrix of episodes was created for all participants to track their explanations across episodes within each pre- and posttest interview. All alternative explanations included direct transcriptions of what students said as warrants for their alternative explanations.

The following are the types of alternative conceptions that were identified in the initial stage of coding student responses, which subsequently became categories of alternative conceptions that were employed in subsequent stages of coding and analysis.

Table 7.
Alternative Conception Categories-Definitions and Student Examples

Types of Alternative Conceptions	
Code	Parent-to-Offspring Transformational
Definition	Describing a process by which the traits of organisms change over time, where the organism bears offspring that are more suited to its environment
When to Use	When explanation references a change in the organism's trait being described as a transformation over a single or multiple generations, where the organism bears offspring that are more suited to its environment
Example	"After a lot of generations, they [the sparrows] would adapt to survive the cold weather. Their babies would be slightly bigger than them. After many generations the babies of the babies of these birds [points to a picture of a small House sparrow on the template displaying House sparrows from a hundred years ago] would grow to the size of this [points to a picture of a large House sparrow on the template displaying House sparrows living in cold places today] to stay warm" (Year 2 Botany-Post).
Code	Anthropomorphic
Definition	Relating to the assignment of human traits, including human agency, to non-human organisms, such as plants and animals
When to Use	When explanation references an organism having a human-like trait, quality, and behavior, including having a psychological trait of conscious desire or feeling (e.g., want, like, try)
Example	"The light parent moths hid behind the tree and tried to hide their offspring behind the tree because they didn't want to get eaten. It doesn't matter what color they are. The light moths and dark moths, they have family, and they will try to help each other out" (Year 1 Animal Behavior-Post).

Types of Alternative Conceptions	
Code	Teleological
Definition	Describing an organism, object, action, or event as directed to a certain goal or to fulfill a certain function
When to Use	When explanation references the eventual purpose of an event as the actual mechanism to explain the phenomenon or when explanation references an organism, action, or event as directed to a certain goal or to fulfill a certain function
Example	I: "Why else might the kelp live there?" S: "For other animals to have it to eat it" (Year 1 Animal Behavior-Pre).
Code	External Agency
Definition	Relating to agents or forces, such as God, mother nature, people, scientists, who are playing a role in the creation of new kinds or the transformation of organisms
When to Use	When explanation references an agent outside of the organism is playing a role in the creation or evolution of an organism or population
Example	"Because they were invented by God in a cold place that's what I think, because the first one [sparrow] was born in the cold place" (Year 2 Botany-Pre).
Code	Lamarckian
Definition	Describing an offspring's inheritance of parents' acquired trait
When to Use	When explanation refers to the offspring inheriting a trait from its parent that is acquired during the parent's lifetime.
Example	"That means that they'll be faster than their parents. Because cheetahs start off as a baby, right? And it's about I don't know maybe a little slower than their parents. But then they get faster, well maybe fast as their parents when they're babies, when they're able to run. But they'll get faster eventually, right? And their babies will be more faster. Because it kept on inheriting. Well they start off as fast as their parents when they're able to run. And then they got faster and then the same thing happened with their children, and the same thing happened with the other generations and the other other generations." (Year 1 Botany-Post)
Code	Cyclical
Definition	Describing the distribution of traits in a population as revolving in a back-and-forth pattern over one or more generations
When to Use	When explanation mentions a back-and-forth pattern as reason for a flip-flop shift of distribution over multiple generations
Example	"Cause guppies rainbow [points to generation 1], guppies silver [points to generation 2], guppies rainbow [points generation 5]. It's a cycle. And then after these [points to generation 5] it goes all the way down the hallway [referring to placing more prediction templates down the hallway, the interviewing space], it's like a pattern, rainbow, silver, rainbow" (Year 1 Botany-Post).

Parent-to-Offspring Transformational. Students who express this conception indicate that the traits of organisms can change over a single or multiple generations, with the organism bearing offspring that are more suited to their environment. The implication is that individual organisms, whether fit or unfit, will adapt to the environment by bearing offspring with an advantageous trait. This conception is related to the idea of transformationism that is commonly found in the literature (Mayr, 2001; Shtulman, 2006). Both conceptions identify the mechanism of change occurring in the process of bearing offspring that is more suited to its environment. However, the process by which transformationsim occurs happens in lockstep within the species group as a whole. The parent-to-offspring transformation accounts for trait changes from parent to offspring that occurs within individual organisms in a population that can either be homogenous or heterogenous in trait distribution.

Anthropomorphic. Participants who express anthropomorphic conceptions display in their explanations an assignment of human traits to non-human creatures, such as plants and animals, to explain an evolutionary phenomenon. These human traits can also include psychological traits, such as wanting or trying. For example, a student explains the change in distribution of traits from a mix of striped and black-winged butterflies in one generation to all black-winged butterflies 50 generations later by explaining, "The striped ones didn't want to get hurt by the birds so they flew away."

Teleological. Teleological conceptions can be expressed in two forms. One form describes an organism, action, or event as directed to a certain goal or to fulfill a certain function. An example of this is found in one student's response when he explains that kelp lives where it lives "so sea otters can eat them." Another form of teleology uses the eventual purpose of an event as the actual mechanism to explain the phenomenon. One student's response, for instance, expresses this form of teleology when he explains, "The cheetahs got faster because they needed to run faster to get away from their predators so they can survive."

External Agency. Students who express external agency conceptions describe agents or forces, such as God, mother nature, people, scientists, as playing a role in the creation of new kinds or the transformation of organisms. One student reasoned, for example, that House sparrows today are larger than they were from a hundred years ago, "Because they were invented by God in a cold place that's what I think, because the first one was born in the cold place."

Lamarckian. This code is applied when a student's explanation refers to the offspring inheriting a trait from its parent that is acquired during the parent's lifetime. This concept is considered more sophisticated than the other alternative conception categories, as it requires of the student knowledge about the survival advantage of certain traits and an idea of inheritance, albeit flawed.

Cyclical. This type of conception is expressed through an explanation that describes the distribution of traits in a population as revolving in a back-and-forth pattern over one or more generations. This type of explanation is the only alternative conception that was not found elsewhere in the evolution education literature. It may be unique to this study because of a unique assessment instrument that asks of students to generate a prediction of the population one, three and five generations later, a question which may reveal this type of reasoning.

Second Strand of Analysis

To illustrate the changes and persistence of students' alternative conceptions across their pre- and posttests, I have developed four case studies. In the studies, I map out both the alternative and normative conceptions for each student across his or her interviews. Within each interview, the case studies focus on four factors: (1) the ideas employed by the student, highlighting the alternative conceptions and normative ideas, (2) the consistency and variability of the students' alternative conceptions across the range of tasks within an interview prompt, (3) the extent to which the context of the tasks plays a role in the variability or consistency observed, and (4) the changes or persistence of alternative conceptions within and across the two (in one case, four) interviews.

Case study selection criteria. The four analysis chapters focus on the interviews from specific cases. For Chapters Four through Seven, I selected from the available corpus of data four students for analyzing the changes and persistence of alternative conceptions from pre- to posttest. I selected these four students for the following reasons:

1. These students are canonical cases. Their interviews represent the following patterns that emerged in the cohort-level analysis:
   A) A general decline of alternative conceptions from pre to post-test, and
   B) A persistence of alternative conceptions in certain contexts or tasks in both pre- and posttests.

   Thus, they provide a lens on the particular patterns that emerged in the cohort-level analysis.
2. In relation to each other, each case displays a different pathway through which their conceptual thinking changes from pre- to posttest.
3. The students were responsive to the questions asked in the interview. Rather than stating, “I don’t know” in response to items they found difficult, they were expressive of their thinking, providing enough evidence for their internal mental processes.

Episode Selection. In each of the four cases selected for comprehensive analysis I chose five to six out of seven tasks in my selection of episodes from the interviews to demonstrate different aspects of the student’s pre- and posttest responses. While I did not include every question asked of the student, those I did include are presented in the order they were asked thus providing a chronologically accurate representation of the student’s conceptual progression through the interview. Episodes selected for inclusion in the case study met the following criteria:

1. The selected episodes display a wide enough range of varied contexts to demonstrate identifiable consistency or variability in alternative conceptions across the range of tasks.
2. The selected episodes present a cumulative view of the student’s responses consistent with the overall conduct of his or her interview.

Given the inclusive range of these criteria, the case studies incorporated most of the episodes in the interviews selected. The few excluded episodes were those in which the students were unresponsive or in which their answers repeated patterns of reasoning better represented by other episodes.

Chapter 3: Results and Discussion: First Strand of Analysis

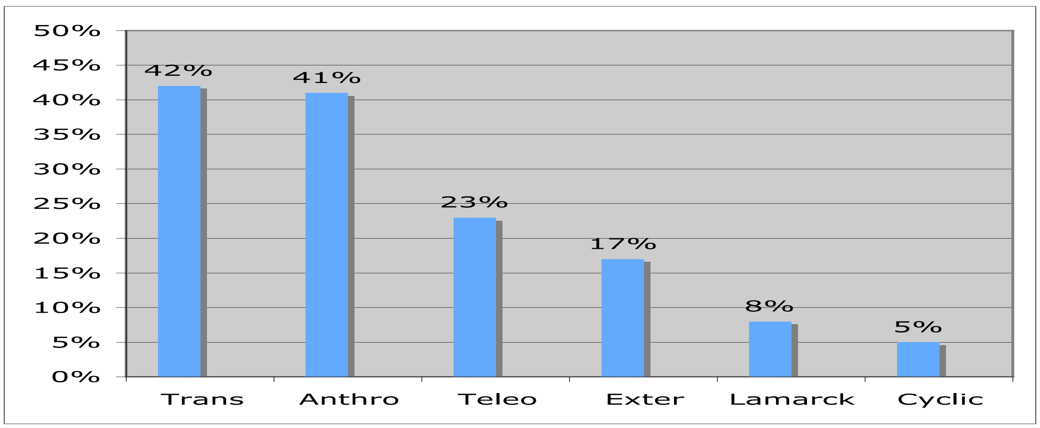
In this chapter I address the findings from my first strand of analysis in relation to my four research questions.

What Are the Alternative Conceptions that Young Children Have about Evolution?

An analysis of the pretests of both years indicates that the second and third-grade students in this study harbor alternative conceptions that are closely related to those held by secondary and university students (See Figure 2). The alternative conceptions that the participants expressed are elaborated below.

Figure 2.

Pretest Analysis of Animal Behavior and Botany 2009 and 2010 Students' Alternative Explanations (% of Students Generating One or More Alternative Explanation Type, n=60)



Parent-to-offspring transformationism (PTOT). Students who displayed this conception expressed the idea that individual organisms transform over time, through a process of bearing offspring with traits that are more suited to their environment than their parents. Forty-two percent of the students from both cohorts combined expressed this conception one or more times in their pretest interview (see Figure 2).

The examples of PTOT conceptions below are student responses (G2 = second grade, G3 = third grade) to the question "How come the sparrows that live where it's cold are bigger than the ones that first got there a long time ago?"

> Maybe the next generation they hatched and got a little bigger. (G2)

> They might be a little bit bigger than their parents and they'll have babies that'll be a little bit bigger than them and then it will go to this [points to picture of large House Sparrow]. (G3)

Parent-to-offspring transformationism is a conception that is closely related to but distinct from the idea of transformationism commonly found in the evolution literature (Mayr, 1999, 2002). Transformationism describes the essences of species changing as a whole through the process of bearing offspring that are more suited to their environment. Parent-to-offspring transformationism borrows from classic transformationism the idea that organisms change through the process of bearing offspring with more advantageous traits. However, it does not attempt to explain the change of essences on a species level. Parent-to-offspring transformation can account for trait changes from parent to offspring that occur within individual organisms in a population that can either be homogenous or heterogeneous in trait distribution.

Anthropomorphism. A student who attributed human characteristics to plant and animal organisms as a means to explain evolutionary change was considered to have expressed an anthropomorphic conception. Forty-one percent of the students from Year One and Year Two expressed this type of conception in their pretest interviews. The examples of anthropomorphic conceptions below are student responses to the question "How come cheetahs today are so much faster than their ancestors?"

> Maybe they kept trying and never gave up. And finally they got really fast and they can catch their prey. (G2)

> The newer cheetahs practiced running more than the older ones. (G2)

The relatively high percentage of students eliciting this conception in their pretests aligns with the findings of evolution education studies that indicate how common anthropomorphism is among secondary and university students in their explanations of evolutionary change (Jungwirth, 1977; Tamir & Zohar, 1991, Demastes, Peebles et al, 1995).

Teleology. Participants who expressed teleological conceptions either described an organism or event as directed towards a certain goal or used the eventual purpose of an event as the actual mechanism to explain the phenomenon. Twenty-three percent of the participants from both cohorts expressed this type of conception in their pretest interview. The example of teleological reasoning below is a student response to the question "Why do you think kelp lives there?"

> Kelp lives there so sea otters can grab at it so the otters won't drown. (G3)

The following example is a student response to the question "How come plants fit so well where they live?"

> They evolved because they needed to evolve to survive. They're now able to survive where they live. (G3)

The presence of teleological conceptions in students' responses is in accordance with past work accomplished in this area (Bishop & Anderson, 1990; Demastes et al., 1996; Tamir, 1985). Tamir and Zohar (1991) found that 71 percent of the tenth graders and 56 percent of the 12th graders in their study used teleological reasoning when giving explanations of evolutionary change. Southerland and her associates (2001) report that the most prominent category of response to evolutionary questions at the second, fifth, eighth, and 12th grade levels was teleological.

External Agency. Students who expressed this conception attributed evolutionary change to an external agent, such as God or people. Seventeen percent of the students in this study evoked an external agency conception in their explanations of evolutionary phenomena during their pretest interview. The following example is a student answer to the question "How come the sparrows that live where it's cold are bigger than the ones that first got there a long time ago?"

> Nice people knew that this place is cold. They used science to make them bigger. (G3)

The next example is an explanation to the question "How come cheetahs today are so much faster than their ancestors?"

> They got to run faster because people train them. (G2)

The example below is a student response to the question "How come plants fit so well where they live?"

> Some scientists made some new kinds of seed and planted it into the ground and made these plants to fit well. (G2)

The occurrence of external agency conceptions relates to but is distinct from the findings of studies conducted by Evans (2000) and Samarapungavan and Weirs (1997). Both studies concluded that most children appeal to creationist explanations when asked about the origins of species. In the present study, students appealed not just to God, but also to other external agents, such as Mother Nature, scientists, and even everyday people, to explain various forms of evolutionary phenomena (e.g., the state of equilibrium in the natural world, change in species kind, change in the distribution of traits in a population).

Cyclical Conceptions. The only alternative conception category that is unique to this study is what I denote a "cyclical" conception. The idea behind this conception is that a back-and-forth pattern dictates the distribution of traits in a population. Cyclical reasoning was observed in five percent of students' answers. The examples below are student explanations to their predictions for the population of guppies in the fifth generation.

> In every generation, they change color. [The fifth generation] is going to look like the first generation again. (G2)

> It's the old switcheroo. Because see guppies rainbow, guppies silver, guppies rainbow [points to three templates displaying the first, second, and fifth generation of guppies]. It's a cycle. (G3)

This type of conception was evoked in response to items that asked the student to make and explain two predictions for the population of organisms over several generations. One explanation of why this type of conception is unique to this study may be the nature of the assessment instrument that was developed for the larger study. There are no known studies in evolution education that employ assessment tasks asking participants to make two predictions for a population of organisms—one prediction for the second generation and another for some generations later, varying from the fifth to the fiftieth across the tasks.

Lamarckian. Students who described the inheritance of a parent's acquired trait to explain evolutionary change are considered to maintain a Lamarckian conception. Eight percent of the students in the study expressed this conception in their pretest interview. The following are examples of Lamarckian explanations to the question "How come cheetahs today are so much faster than their ancestors?"

> They'll keep on hunting for food and keep on running and maybe their bones will grow. And then when they have babies, their legs will be bigger and they keep on running and it keeps on going. (G3)

> The babies of these [points to picture of cheetah], their legs would probably grow longer because they got it from their parents who ran faster to catch the gazelle. If there's something that will run faster and that's what it [the cheetah] likes to eat, then it would run faster and their babies would run faster. (G3)

The research literature also identified Lamarckian conceptions in university students' explanations of evolutionary phenomena (Bizzo, 1994; Brumby, 1979; Deadman and Kelly, 1978; Jimenez-Alexaindre, 1992).

How Do Young Children's Alternative Conceptions Change or Persist after Their Participation in an Instructional Course that Scaffolds the Mechanism of Natural Selection Through Cases of Microevolution?

The analyses of pre- and posttest changes in alternative conceptions across students were examined at multiple levels to provide a sense of the patterns that were occurring within each year. The first level compared the combined pre- and posttests of both cohorts, totaling 60 sets of pre- and posttest interviews (see Figure 3). The second level compared the pre- and posttests of the two cohorts separately, given that the second cohort was administered a different assessment instrument (see Figures 4 and 5).

Figure 3 presents the percentage of students who displayed one or more alternative explanation by type from pre- to posttest. With the exception of the Lamarckian and cyclical categories, the frequency of alternative conceptions expressed declined from pre- to posttest. More specifically, we see that the most common types of alternative conceptions occurring across the two cohorts in their pretests are parent-to-offspring transformational (42%), anthropomorphic (41%), and teleological (23%). We also see how those percentages roughly decline by half in the posttests, with 19%, 19%, and 12% of the participants respectively expressing one or more transformational, anthropomorphic, or teleological explanation.

Figure 3.
Pre- and Posttest Analysis of Animal Behavior and Botany 2009 and 2010 Students' Alternative Explanations (% of Students Generating One or More Alternative Explanation Type, n=60)

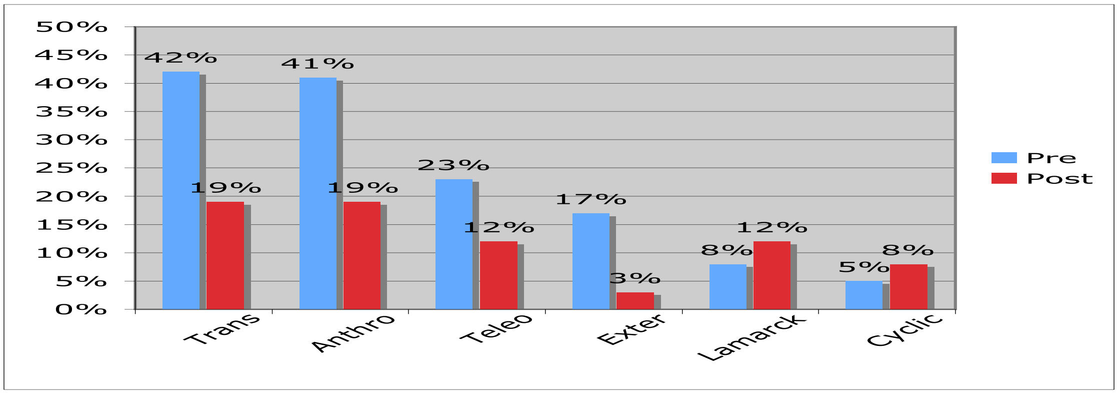


Figure 4.
Pre- and Posttest Analysis of Animal Behavior and Botany 2009 Students' Alternative Explanations (% of Students Generating One or More Alternative Explanation Type, n=29)

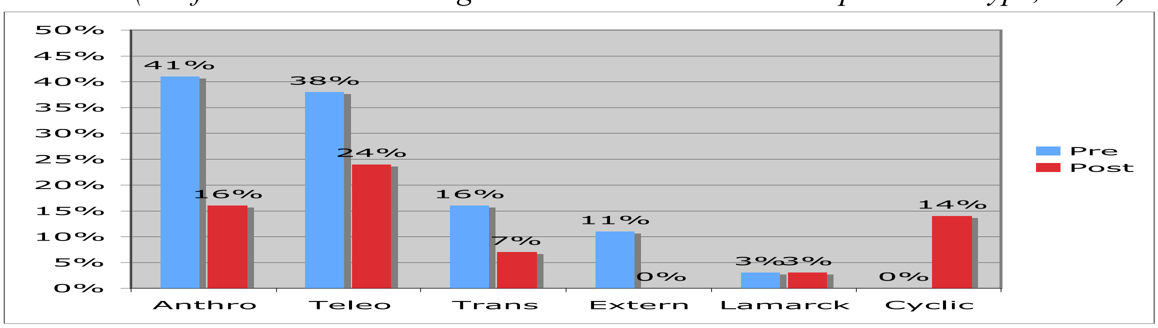
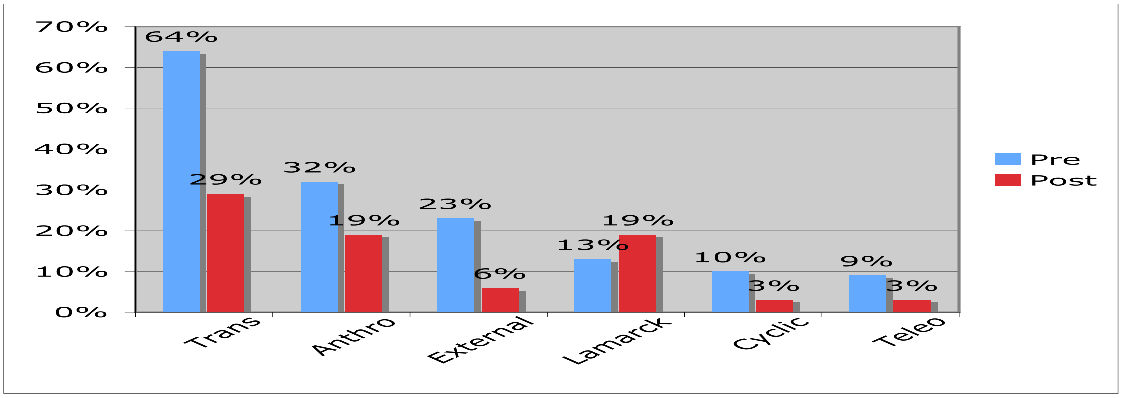


Figure 5.
Pre- and Posttest Analysis of Animal Behavior and Botany 2010 Students' Alternative Explanations (% of Students Generating One or More Alternative Explanation Type, n=31)



One explanation for the significant decline in parent-to-offspring transformationism from pre- to posttest is that the scaffolding of inheritance in the instructional course may have helped students understand that offspring tend to resemble their parents. This understanding of basic inheritance may have mitigated the conception that organisms can bear offspring with more advantageous traits than themselves.

The relatively high frequency of anthropomorphic conceptions expressed in the pretests and its decline in the posttests may again be a result of the effectiveness of the instructional intervention. The students' developing understanding of the mechanism of natural selection may have diminished their tendency to rely on anthropomorphic interpretations of evolutionary change. This interpretation of the trend is supported by the findings in child psychology studies that suggest young children are predisposed to reason in terms of human psychological attributes in the absence of a mechanistic understanding of biological phenomena (Carey, 1995; Inagaki & Hatano, 2002).

The decrease in external agency and teleological conceptions from pre- to posttest invites a similar explanation. Scaffolding the mechanism of natural selection and its prerequisite notions, such as variation, inheritance and differential survival, through cases of microevolution may have been effective in discouraging students from invoking the intervention of an external agent to explain evolutionary change. Likewise, students may rely less on teleological reasoning, that is, using an eventual purpose of an event as the actual mechanism to explain the phenomenon, once they have an understanding of and can apply the process of natural selection to explain evolutionary change.

Figure 3 reveals a modest increase in the frequency of cyclical conceptions from pre- to posttest. One explanation for this anomalous increase is that through instruction students might have acquired a misinterpreted understanding of how a change in distribution of traits can occur. The curriculum aimed to scaffold the idea that a change in environmental conditions could lead to a shift in distribution of traits over one or several generations. Some students, however, may have developed on their own an idea that a bi-directional shift in distribution would continue to occur in a back-and-forth pattern, regardless of stability in the environmental conditions.

Another type of conception that showed a subtle increase in frequency from pre- to posttest was the Lamarckian. This could be attributed to the fact that Lamarckian reasoning is relatively sophisticated in comparison to the other types of alternative conceptions that were evoked by the students in this study. It requires the student to recognize the potential impact of an environmental press on the population and to have an understanding of the survival advantage of a trait in relation to that environmental press. Exposure to the curriculum may have helped many students develop these principles. A few, however, may have acquired a misconstrued understanding of inheritance that led them to believe that the offspring will inherit the parent's acquired trait. This upward trend from pre- to posttest is aligned with studies that have found a majority of college students harboring Lamarckian conceptions even after they have taken one or more courses in biology (Bizzo, 1994; Brumby, 1979; Deadman and Kelly, 1978; Jimenez-Alexaindre, 1992).

The overall findings in the pre- to posttest analysis provide an existence proof that young children's alternative conceptions can change and be reduced by their participation in the larger project's instructional intervention, which aimed to scaffold the conceptual underpinnings of natural selection through cases of microevolution. The subsequent case study chapters will explore in detail the various pathways by which four individual students' alternative conceptions decline from pre- to posttest in relation to the development of their conceptual understanding of natural selection.

How Variable or Consistent are Children's Alternative Conceptions across the Range of Tasks in an Interview?

Students' answers were analyzed to observe whether there was consistency or variability in their explanations across the range of tasks in their interview. For instance, did students appeal to one alternative conception consistently across the range of tasks in a single interview or did they appeal to multiple conceptions depending on the context of the problem? Consistency of alternative conceptions was determined by observing whether the participant expressed only one type of alternative conception within the span of his or her entire interview. The student must have invoked the single alternative conception type more than once in the interview in order for it to be considered consistent. Variability of alternative conceptions was determined by noting whether participants expressed only one type of alternative conception within the span of their entire interview. As mentioned in the Methods chapter, I operationalized additional instances of an alternative conception as either a repeat of an alternative conception reflected in a prior item or as an alternative conception new to the interview.

Table 8 below shows the number of interviews that display either a consistency or variability in the participant's expression of alternative conceptions within a single interview. The range in number of instances of alternative conceptions that were coded within a single interview is 0 to 13, with a mean of two instances per interview. The table also displays the number of students who expressed one alternative conception and those who did not express any alternative conceptions in their interview. Students who were not coded for any alternative conceptions either reflected partially normative responses (e.g., "The plants need water and the sun to live") or were silent or made statements such as "I don't know."

Table 8 shows that among the interviews where participants were coded for two or more alternative conceptions, 26% (n=15) reflected consistency and 74% (n=42) reflected variability in their expression of alternative conceptions within an interview prompt. Not surprisingly, consistency was reduced among the students reflecting the greatest number of instances of alternative conceptions. For instance, the 13 students displaying five or more instances of alternative conceptions were entirely variable in their expression of alternative conceptions.

Table 8.

Frequency Distribution of Consistency and Variability of Students' Alternative Conceptions, *Sorted by Total Number of Instances of Alternative Conceptions Coded Within an Interview (n*=120)*

Total Number of Instances of Alternative Conceptions Coded in Interview	0 (n*=36)	1 (n*=27)	2	3	4	5	6	7	10	13	Total
Consistent			11	2	2	0	0	0	0	0	15
Variable			13	10	5	8	2	1	1	2	42

*Note. n=number of interviews

The results of this analysis reveal that a plurality of alternative conceptions were more commonly expressed by the participants in their explanations of evolutionary phenomena. The shifting pattern of alternative conceptions documented in this study seems to indicate that young students' conceptual frameworks in this area are unstable.

The variable quality of students' responses could be attributed to the nature of the assessment instrument. The tasks that made up the interview varied in content and structure. Some tasks were about plants, others were about animals. Some tasks focused on cases of microevolution over one to 50 generations while others focused on cases of evolutionary phenomena, in which the time frame spanned over 100 years or thousands of years. The question prompts varied, asking the students to explain the current state of equilibrium, to make predictions about future populations, or to explain the change in species-kind over time. This wide array of varied contexts within the interview prompt may account for the pattern of variable reasoning that emerged. The context effects documented in this study are aligned with the findings of diSessa, Gillespie, and Esterly's quasi-replication (2004) of Ioannides and Vosnaidou's study (2001). DiSessa and his colleagues found that when new contexts were introduced in the quasi-replicative study, students' responses were inconsistent across contexts and that assessing students' understanding in a limited number of contexts may overestimate students' knowledge coherence.

Students' interviews were also analyzed to observe possible patterns of co-occurrence across alternative conceptions within a single interview. For instance, did students tend to appeal to a certain combination of alternative conceptions more often than others?

A co-occurrence of two alternative conception types was determined by observing whether the participant expressed two or more different alternative conception categories within a single interview. Within these interviews of variable responses each combination of expressed alternative conception was noted.

Table 9 below shows the number of interviews that display a combination between two alternative conception categories. The most frequent combinations were the following: PTOT and anthropomorphism, PTOT and teleology, and teleology and anthropomorphism. These findings suggest that students who tend to posit that organisms will bear offspring more suited to their environment also tend to attribute human characteristics to organisms. Similarly, students who tend to posit that organisms will bear offspring more suited to their environment also tend to explain evolutionary phenomena in terms of their function or purpose. Closing the circle, students who tend to explain evolutionary phenomena in terms of their function or purpose also tend to attribute human attributes to the organisms in that phenomenon.

Table 9.
Frequency Distribution of Co-occurrence of Alternative Conception Categories Within an Interview, Sorted by Total Number of Instances of Combination of Alternative Conception Categories Occurring Across Episodes Within an Interview (n=120)*

	Trans	Anthro	Teleo	Exter	Lamar	Cyclic
Trans	0	13	9	4	1	1
Anthro	13	0	9	5	3	3
Teleo	9	9	0	1	0	1
Exter	4	5	1	0	1	1
Lamar	1	3	0	1	0	0
Cyclic	1	3	1	1	0	0

*Note. n=number of interviews

In addition, students' responses were analyzed to observe possible patterns of co-occurrence within each episode. A co-occurrence of two alternative conception categories was determined by observing whether a student expressed two categories within a single explanation. It should be noted that there were no instances of students expressing more than two alternative conception categories within one episode.

Table 10 below shows the number of episodes in which participants expressed a combination of two alternative conception categories. The most frequent co-occurrence of alternative conceptions was that of anthropomorphism and teleology. This suggests that students who explained an evolutionary phenomenon in terms of function or purpose also attributed human characteristics to those organisms within that phenomenon.

Table 10.
Frequency Distribution of Co-occurrence of Alternative Conception Categories Within an Episode, Sorted by Total Number of Instances of Combination of Alternative Conception Categories Occurring Within an Episode (n=120)*

	Trans	Anthro	Teleo	Exter	Lamar	Cyclic
Trans	0	1	2	2	0	0
Anthro	1	0	11	5	2	0
Teleo	2	11	0	0	0	0
Exter	2	5	0	0	0	0
Lamar	0	2	0	0	0	0
Cyclic	0	0	0	0	0	0

*Note. n=number of interviews

Relevant to this point, Tamir and Zohar (1991) have found in their study on the relation between anthropomorphic and teleological formulations among high school students that there appears to be a kind of teleological reasoning that is closely related to anthropomorphism. This relation, according to them, is based on the belief in the functionality of behaviors of living organisms, which is demonstrated by major principles, such as the adaptability of organisms to their environment. Tamir and Zohar also regard teleology as a particular instance of anthropomorphism since, they note, "as suggested by Hempel (1965), the teleological explanation makes us feel that we really understand the phenomenon at hand because the explanation is given in terms of purposes and intentions which fit the way we are accustomed to view our own purposeful behavior" (p. 58). Similarly, Taber and Watts (1996) proposed a division of anthropomorphism into two classes: one is a weak, or metaphorical, class that uses intentionality or human characteristics to communicate ideas in analogy with a social being, the other is a strong class, which is teleological and allows phenomena to be explained in terms of non-existent intentionality in the entities involved to achieve the end state. These studies suggest that the strong relationship between intentionality and purpose in students' reasoning could account for the frequent co-occurrence between anthropomorphism and teleology that was found in the explanations by the participants in this study.

To What Extent Can Context Account for the Patterns that Emerge in Students' Explanations?

Because this study is concerned with the contexts in which alternative conceptions are invoked, part of my analysis includes a close examination of the patterns that emerge from the contexts of the assessment tasks. I examine how frequently each type of alternative conception was invoked within the context of each assessment item, and in the section below I provide interpretations of the interplay between context and PTOT, anthropomorphic, and teleological reasoning. As shown in the tables below, these three types of alternative conceptions yielded the most salient contextual patterns.

Tables 11 and 12 are a set of matrices displaying by row the episodes from each year's assessment items. The columns in each matrix display the six alternative conception types. Each cell presents the number of instances a particular alternative conception was invoked in a particular context.

Table 11 displays the episodes found in the pretest of Year One and presents the instances of alternative conceptions invoked by participants in both the Animals and Botany class in Year One. Table 12 displays the instances of alternative conceptions that were invoked in the contexts of the posttest assessment items for the Year One cohort.

Table 11.
Number of Alternative Conceptions Expressed by Type in each Episode in Pretest for Year One (n=29)

PRETEST	Trans	Anthro	Teleo	Extern	Lamarck	Cyclic
Sea Otter Lives Where it Lives Explanation	0	2	0	0	0	0
Kelp Lives Where it Lives Explanation	0	0	11	2	0	2
Cricket/*Brassica Rapa* 2nd Generation Prediction and Explanation	0	2	0	0	0	0
Moth 20th Generation Prediction and Explanation	1	2	0	0	0	0
Moth Empirical Feedback Explanation	1	0	0	0	0	0
Moth Dynamic Assessment	0	0	0	0	0	0
Moth Return to Original Puzzle	2	0	0	0	0	0
Moth Revoicing	0	0	0	0	0	0
Guppy 2nd Generation Prediction and Explanation	0	2	0	0	0	0
Guppy Empirical Feedback Explanation	0	2	0	0	0	0
Guppy 5th Generation Prediction and Explanation	1	1	0	0	0	0
Cheetah Change in Running Speed Explanation	0	5	0	0	0	0
Cheetah Dynamic Assessment	0	1	0	1	0	1
Cheetah Return to Original Puzzle	1	1	0	0	1	0
Cheetah Revoicing	0	1	0	0	0	0

Table 12.
Number of Alternative Conceptions Expressed by Type in each Episode in Posttest for Year One (n=29)

POSTTEST	Trans	Anthro	Teleo	Extern	Lamarck	Cyclic
Sea Otter Lives Where it Lives Explanation	0	1	0	0	0	0
Kelp Lives Where it Lives Explanation	0	0	9	0	0	0
Cricket/*Brassica Rapa* 2nd Generation Prediction and Explanation	0	0	0	0	0	0
Moth 20th Generation Prediction and Explanation	0	1	0	0	0	0
Moth Empirical Feedback Explanation	0	1	0	0	0	0
Moth Dynamic Assessment	0	1	0	0	0	0
Moth Return to Original Puzzle	0	0	0	0	0	0
Moth Revoicing	0	0	0	0	0	0
Guppy 2nd Generation Prediction and Explanation	0	1	0	0	0	1
Guppy Empirical Feedback Explanation	0	1	0	0	0	0
Guppy 5th Generation Prediction and Explanation	0	1	0	0	0	4
Cheetah Change in Running Speed Explanation	3	3	0	0	1	1
Cheetah Dynamic Assessment	0	0	0	0	1	0
Cheetah Return to Original Puzzle	1	0	0	0	1	0
Cheetah Revoicing	0	1	0	0	1	0

Tables 13 and 14 display the episodes found in the pretest and posttest respectively of Year Two and presents the instances of alternative conceptions invoked by participants in both the Animals and Botany class of Year Two.

Table 13.
Number of Alternative Conceptions Expressed by Type in each Episode in Pretest for Year Two (n=31)

PRETEST	Trans	Anthro	Teleo	Extern	Lamarck	Cyclic
Rainforest Plants in Desert Explanation	0	0	1	0	0	0
Desert Plants in Rainforest Explanation	1	0	1	0	0	0
Desert Plants in Desert Explanation	0	0	0	2	0	0
Cricket/*Brassica Rapa* 2nd Generation Prediction and Explanation	4	0	1	1	0	0
Cricket/*Brassica Rapa* 7th Generation Prediction and Explanation	3	0	1	1	0	2
Guppy 2nd Generation Prediction and Explanation	1	2	0	0	0	0
Guppy Empirical Feedback Explanation	1	2	2	0	0	0
Guppy 5th Generation Prediction and Explanation	0	1	0	0	0	2
Butterfly 50th Generation Prediction and Explanation	0	2	0	0	0	1
Butterfly Dynamic Assessment Part 1	1	0	0	0	0	0
Butterfly Dynamic Assessment Part 2	2	0	0	0	0	0
Butterfly Revoicing	1	1	2	0	0	1
Sparrow Change in Body Size Explanation	5	1	4	2	2	0
Sparrow Dynamic Assessment Part 1	1	0	1	0	2	0
Sparrow Dynamic Assessment Part 2	2	1	2	0	1	0
Sparrow Revoicing	8	0	2	0	0	0
Cheetah Change in Running Speed Explanation	10	6	2	0	2	0
Desert Plants Fit Explanation	1	4	2	2	0	0

Table 14.
Number of Alternative Conceptions Expressed by Type in each Episode in Posttest for Year Two (n=31)

POSTTEST	Trans	Anthro	Teleo	External	Lamarck	Cyclic
Rainforest Plants in Desert Explanation	0	0	0	0	0	0
Desert Plants in Rainforest Explanation	0	0	0	0	0	0
Desert Plants in Desert Explanation	0	0	0	0	0	0
Cricket/*Brassica Rapa* 2nd Generation Prediction and Explanation	0	0	0	0	0	0
Cricket/*Brassica Rapa* 7th Generation Prediction and Explanation	0	0	0	0	0	0
Guppy 2nd Generation Prediction and Explanation	0	0	0	0	0	0
Guppy Empirical Feedback Explanation	0	0	0	0	0	0
Guppy 5th Generation Prediction and Explanation	0	0	0	0	0	1
Butterfly 50th Generation Prediction and Explanation	0	0	0	0	0	0
Butterfly Dynamic Assessment Part 1	0	0	0	0	1	0
Butterfly Dynamic Assessment Part 2	0	0	0	0	0	0
Butterfly Revoicing	0	0	0	0	0	0
Sparrow Change in Body Size Explanation	5	1	1	2	0	0
Sparrow Dynamic Assessment Part 1	0	1	1	0	0	0
Sparrow Dynamic Assessment Part 2	6	0	0	2	2	0
Sparrow Revoicing	4	1	1	0	1	0
Cheetah Change in Running Speed Explanation	3	4	1	0	3	0
Desert Plants Fit Explanation	2	3	1	1	1	0

The contexts of parent-to-offspring transformational (PTOT) reasoning. As we look at the pretest tables (Tables 11 and 12) of both cohorts, we see that PTOT conceptions were expressed across the range of tasks for both years. The posttest tables for both cohorts (Tables 13 and 14), however, show that students tended to express PTOT conceptions in items that asked them either to explain the change in species-kind over time or to explain the current state of fitness between organisms and their environment. The students did not express PTOT conceptions in the items that involved predictions and explanations for microevolutionary change.

One explanation for the significant decrease in PTOT conceptions from the pre- to posttest in the contexts of microevolutionary change is that students could more easily apply their understanding of inheritance, differential survival and reproductive value (all of which were scaffolded in the instructional intervention) to a system level of population where within-kind variation is relatively transparent (i.e., dichotomous traits were introduced in the stem of the task). In those contexts where students were asked to consider the change of organism kind on a species level (e.g., cheetah, sparrow, and desert plant tasks), the variation was relatively non-transparent (i.e., a continuous trait was introduced in the stem of the task), which may have led students to fall back on PTOT reasoning when they could not see the potential application of the concepts that were scaffolded in the intervention to these cases of evolutionary phenomena.

The contexts of anthropomorphic reasoning. Anthropomorphic explanations appeared across multiple contexts in both cohorts. However, a relatively high number of anthropomorphic explanations was generated in the context of the cheetah question that asked students, “How come most cheetahs today are able to run so much faster than their ancestors, the ones that lived a long time ago?” An example of a common anthropomorphic response to this question is, “The newer cheetahs taught each other how to run and they practiced everyday and raced each other” (second-grade student, Year One pretest). The number of anthropomorphic responses remained relatively high from pre- to posttest in the cheetah task.

One reason for this high frequency could be the phenomenal setting of the task, which was atypical in relation to the other tasks in the interview. While all other tasks concerned either a change in the anatomical features of animals or the equilibrated state in the structure of plants in relation to their environment, the cheetah problem alone required students to consider a change not in an anatomical feature, but in an organism's physical capacity (running speed) over time. It could be that children are more likely to ascribe effort or other psychological characteristics to explain evolutionary change when the targeted trait appears to be malleable.

The contexts of teleological reasoning. In both cohorts teleological conceptions were expressed in students' explanations of evolutionary phenomena. When we look at the pretest in Year Two (Table 13), we see that teleological explanations were invoked across the range of tasks. In Year One (Table 11), however, we see that all of the teleological explanations that were invoked in the pre- and posttest were found in the kelp item. In this context, participants were told that "kelp is a type of plant that lives in the sea" and asked, "Why do you think kelp lives there?" An example of a common teleological response to this question is "Kelp lives there for the other animals to have it, to eat it" (third-grade student, Year One pretest).

One explanation for this contextual pattern is that the kelp item was the only item in the assessment instrument of both years that asked a "why" question (i.e., "Why do you think kelp lives there?") while all the other tasks asked a "how" question. Once that item was substituted with the rainforest and desert plants task (which was akin to the sea otter and kelp task in that it was designed to have students explain the state of equilibrium between organisms and their environment) in the 2010 interview, we witnessed a significant decline in the frequency of teleological explanations (see Figure 13). These findings indicate that young children are more likely to express teleological conceptions in the context of a "why" question. This is consistent with Kelemen's work on teleological explanations, which have demonstrated that young children are prone to teleological reasoning in their explanations about the natural world (1999, 2004). The questions that were posed to the participants in her study (1999) were also commonly "why" questions (e.g. "Why are rocks pointy?").

Summary of Results and Discussion in the First Strand of Analysis

A review of the results gleans the following findings. We see that children invoked six alternative conceptions in their pre- and posttests, five of which (parent-to-offspring transformational, anthropomorphic, teleological, external agency and Lamarckian) are common to the literature and one of which (cyclical) appears in the data for the first time in this study. Of these six alternative conceptions, four decline sharply in frequency of expression from pre- to posttest (transformational, anthropomorphic, teleological, external agency) and two show an increase in frequency of expression (Lamarckian and cyclical).

The findings reveal variability in students' expression of alternative conceptions across the range of tasks within an interview. The contexts of the assessment tasks could account for the variability that we observed in students' alternative conceptions. To better understand how these findings play out in individual terms, I next examine four specific students and trace their conceptual changes over the course of instruction.

Chapter 4: The Case of J

"Only their babies can be evolutions."

Overview

We begin with J, a student who makes considerable headway in coordinating his ideas early on in his pretest and improves on that good start in his posttest results (see Tables 15 and 16). As we can see from the table, J is an exemplar of a common pattern among the students in the 2010 cohort, who in their posttests often generate explanations that reveal an understanding of natural selection when the idea of within-kind variation is foregrounded in the stem of the task. Similar to many in his cohort, J's alternative conceptions persist from pre- to posttest in contexts that ask students to explain change over time and that do not foreground the idea of within-kind variation.

If in many respects he is representative of his peers; in one respect he differs. J had exposure to the word "evolution" and had developed his own ideas about the concept prior to the pretest. What precisely that exposure was we do not know. Nor can we determine whether his interpretation is a distortion of what he was taught or if what he was taught was itself non-normative. That the idea of evolution is not entirely alien to him provides a window on how even a rudimentary acquaintance with the subject can both assist and hinder conceptual development. J brings up the terms "evolution" and "evolve" numerous times in both his pre- and posttests. In his pretest answers he uses the words in ways that suggest transformational and teleological reasoning in some contexts and a natural selection understanding in others. However the terms come up more often in contexts where J does not articulate a clear understanding of natural selection.

Many questions arise when we approach J's interviews. Does he perceive the idea of "evolution" in Darwinian terms? Do his preconceptions about "evolution" lead him astray or do they set him on a path toward understanding natural selection? Does his definition of "evolution" change from pre- to posttest or does it remain static? Finally, how precisely does he employ the word "evolution"? Is it shorthand language for natural selection or does he use it as an expression of transformational and teleological reasoning?

His case illustrates the equivocal nature of language when explaining evolutionary phenomena. In several episodes, only tentative interpretations of J's explanations are possible. We can however construe his transformational and teleological explanations as shorthand language for his ideas about natural selection or as a reflection of his actual conceptions and conclude that J holds multiple ideas about evolution that are both normative and non-normative.

Table 15.

Pretest Summary of J's Alternative and Normative Conceptions, Sorted by Episode

Pretest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Terms
BRASSICA RAPA Prediction and Explanation: one generation after arrival of caterpillars	1~Anthropomorphism 2~Transformationism	1~Survival Advantage 2~Change in Distribution	1~Evolution
CRICKET Setting up the case	1~Teleological 2~Transformationism	1~Survival Advantage	1~Evolution

Pretest Episodes	**Alternative Conceptions**	**Normative Conceptions**	**Idiosyncratic Interpretation of Terms**
CRICKET Prediction and Explanation: cricket or *Brassica rapa* one generation after arrival of flies		1~Survival Advantage 2~Reproductive Advantage? 3~Change in Distribution 4~Inheritance	
CRICKET Prediction and Explanation: five generations after arrival of flies		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
GUPPY Empirical Feedback: How is this different? How do you think that happened?	1~Teleological	1~Survival Advantage 2~Change in Distribution	1~Evolution
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	1~Evolution
BUTTERFLIES Revoicing	1~Teleological	1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	1~Evolution
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?			1~Evolution
SPARROWS Dynamic Assessment: Survival Advantage of Trait			
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Inheritance	
SPARROWS Revoicing		1~Survival Advantage 2~Reproductive Advantage 3~Inheritance	
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Teleological	1~Survival Advantage	1~Evolution
DESERT PLANTS Explaining the fit between plants and their environment	1~Teleological	1~Survival Advantage	1~Evolution

Table 16.
Posttest Summary of J's Alternative and Normative Conceptions, Sorted by Episode

Posttest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Terms
BRASSICA RAPA Prediction and Explanation: one generation after arrival of caterpillars		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
BRASSICA RAPA Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance 5~Extinction	
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Teleological	1~Survival Advantage 2~Inheritance	1~Evolution
SPARROWS Dynamic Assessment: Survival Advantage of Trait	1~Teleological	1~Survival Advantage 2~Inheritance	1~Evolution
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Survival Advantage 2~Inheritance	1~Evolution
SPARROWS Revoicing	1~Teleological	1~Survival Advantage 2~Reproductive Advantage 3~Inheritance	1~Evolution
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Teleological	1~Survival Advantage 2~Reproductive Advantage 3~Inheritance	1~Evolution
DESERT PLANTS Explaining the fit between plants and their environment	1~Teleological 2~Transformationism	1~Survival Advantage 2~Inheritance	1~Evolution

J's Pretest: Unpacking Normative and Alternative Conceptions

J employs the term "evolve" and a "need as a rationale for change" heuristic to predict and explain change in population. In the *Brassica rapa* item, the interviewer frames the task by showing J a template displaying a field of *Brassica rapa* plants and points out that many of the plants in this field are smooth (i.e., eight) and a few are hairy (i.e., two). She then brings out icons of caterpillars and lays them on the field, telling J that the caterpillars arrived at the field and began to eat the plants. She adds that scientists have noticed that the caterpillars like to eat the smooth plants and they don't seem to like the hairy ones. The interviewer then asks J for his prediction of what the next generation of *Brassica rapa* plants in the field would look like after the arrival of the caterpillars. The interviewer gives him a blank field template and a stack of 16 hairy and 16 smooth plant icons. J lays down four hairy plants and six smooth plants. He provides the interviewer with the following explanation.

> J: If that was the number [points to generation 1 template] then it would be this [points to his prediction of generation 2 template: four hairy plants, six non-hairy].
> I: So tell me what you got.
> J: I have four hairy plants, and six not-hairy ones.
> I: And how did that happen?
> J: Because there's two hairy ones [pointing to hairy plants in Gen 1] and there's gonna be another two because of these guys [points to caterpillars in Gen 1]. Cause they have a better survival because the caterpillars don't like the hairy ones.
> I: So...how would that happen?
> J: The seeds would evolve and stand up to the caterpillars by growing hairs.

The mechanism of change that J describes does not imply a process of natural selection. Instead he personifies the plants when he says they will "stand up to the caterpillars by growing hairs." "Stand up to the caterpillars" could be either a figure of speech or an expression of the plants' intentionality to evolve and change in response to the arrival of the caterpillars. The transformational element appears when he mentions that the "seeds would evolve and stand up to the caterpillars *by growing hairs* [emphasis added]." In this statement, one can infer that J is expressing the idea that the seeds change or transform when he says they "evolve."

J's anthropomorphism recurs in the task that follows. In this item, the interviewer shows J a template of an island with crickets on it. She points out to J that on this island there were a lot of crickets with ridges on their wings that enabled them to chirp (i.e., 16) and a few that didn't have ridges and were unable to chirp (i.e., four). The interviewer reads to J the narrative of the Kauai crickets. She explains how flies arrived on this island and laid their eggs in the crickets' bodies. As the interviewer tells J that the flies' eggs growing inside the crickets' bodies would eventually kill the crickets, J's eyes light up as he exclaims.

> J: Oh I think I know why, evolution can stand up to the flies!
> I: What was that again?
> J: *Evolution can stand up to the flies* [emphasis added].
> I: Oh, evolution can stand up to the flies? What do you mean?
> J: *Yeah, they're evolving, so they can um. Either these ones* [points to chirping cricket] *from these guys* [points to mute cricket] *to make think, make these guys* [points to fly] *away. Or these guys* [points to mute cricket] *were getting* [far] *so they could fly away. But this one* [points to chirping cricket] *might make something to make it like this* [points to mute cricket] *so this doesn't lay its eggs on it* [points to chirping cricket] [emphasis added].

J has an Aha! moment as he realizes the survival advantage of having "ridge-less" wings and being a mute cricket. He exclaims, "I get it! Evolution can stand up to the flies!" We can infer from this utterance that the ontology of evolution is not referred to as a "process" as it is normatively conceived, but rather as an "entity" as J personifies it by saying it "can stand up to the flies." J's comment illustrates a tendency identified by Ferrari and Chi (1998) to attribute to the evolutionary process in general, and to natural selection in particular, event-like properties. Just as naïve students often focus on the idea of survival of the fittest, embedding the idea within an event ontology that involves actors struggling to overcome obstacles and achieve goals, J here attributes to the "entity" evolution an ability to respond to events, in this case to resist an attack of flies. His use of the words "stand up to," the same words he used to describe the *Brassica rapa*'s resistance to caterpillars, again lends itself to two interpretations. He may be expressing anthropomorphic intentionality or he may be repeating the metaphor he hit upon in his first series of answers.

J's next explanation is partly inaudible as he lays out possible scenarios: "Either these ones [points to chirping cricket] from these guys [points to mute cricket] to make these guys [flies] away or this one [chirping cricket] might make something to make it like this [points to mute cricket] to make so this [fly] doesn't lay its eggs in them." He adds characteristics of intentionality to the chirping crickets, where they "might make something to make it like this [the mute cricket] to make the [flies] go away."

I: Now how do you think the flies find the crickets to lay their eggs in them?
J: Maybe they feel the wings.
I: Or they can listen for their chirps.
J: *Yeah! So they can evolve into this* [points to mute cricket]*, so they can't hear them* [emphasis added].
I: Oh that's interesting. Tell me more about that idea.
J: *And they're slowly evolving, that's why this one* [points to mute cricket]*, these ones don't have ridge things so they don't get killed by the flies* [emphasis added].
[The interviewer continues with the narrative and begins to tell J about the life cycle of crickets]
I: In the wild, crickets mate and have babies.
J: So if these two mate [points to chirping and non-chirping cricket], it'll be little wing-ridge [? -inaudible], little bit not.

In this exchange, the interviewer provides information on how the flies find the crickets. As soon as she hints that they find them by listening for the chirps, J expresses the idea that the chirping crickets will evolve into non-chirping crickets in order to survive. He adds that the chirping crickets will evolve into the mute crickets "so [the flies] can't hear them." He explains why the non-chirping crickets do not have ridges on their wings, "so they don't get killed by the flies." These teleological explanations invoke clearly and unambiguously the idea that evolution occurs in response to the needs of an organism.

In this and the prior episode, J uses the term evolution several times in a way that appears pre-Darwinian. He invokes the idea of evolution through teleological reasoning. His approximation to a mechanism of change is a transformation of an organism's characteristics. He also refers to evolution as an agent or entity that acts with intentionality to "stand up to" the environmental presses.

J explains a shift in population through "mating and multiplying." The exchanges above came before the question of the task. In the next part of the task the interviewer asks J to predict and explain what he thinks the next generation of crickets on the island will look like after the flies have arrived. She gives him a template of a blank island and a set of 16 chirping cricket icons and 16 mute cricket icons. J lays down six mute (or ridge-less) crickets and 14 chirping crickets and explains to the interviewer his prediction.

> J: There are four ridge-less crickets [referring to Gen 1 island], there should be six ridge-less crickets [in Gen 2], and instead of 16 ridged crickets [referring to the number of crickets in Generation 1], then there should be 14 ridged crickets.
> I: How would that happen?
> J: Mmm, [looks at both generations] I think they should actually be different one [takes out two chirping crickets, and puts two mute crickets in]. There should be two, four, six, eight ridge-less crickets and there should be 12 ridged crickets.
> I: How would that happen?
> J: I multiply it by two.
> I: You multiplied it by two?
> J: Ya.
> I: What did you multiply by two? Your math is so quick that I can't even catch up right now.
> J: I multiplied this [points to mute crickets in Gen 1] by two and then subtracted this [points to chirping crickets in Gen 1] by four.
> I: So why did you multiply it by two? What made you think that you should multiply it by two?
> J: Cause each cricket usually, um, has a different cricket with them to mate with and they might have another one so there should be there two or there could be two babies so they can have that, and they die.

It is apparent from J's prediction that he has an understanding of the survival advantage of being a mute, "ridge-less cricket" and how that would affect the distribution of traits in the population. In mid-explanation, he stops to take away two chirping crickets and add two more mute crickets to his prediction, highlighting the salient change in the relative frequency of traits. He multiplies the mute crickets by two and subtracts four chirping crickets from generation one to arrive at the number of chirping and mute crickets in generation two. He explains to the interviewer that he multiplied the mute crickets in generation one by two, because they would "mate" and there "should be two babies." It is implicit in his explanation that he has an understanding of the reproductive advantage of being a mute cricket as well as the idea of offspring resembling their parents through their inheritance of traits.

There are notable differences in J's explanations between this and the previous episode. Here in working with icons to represent the population, J doesn't bring up the term "evolution" and there are no hints of teleological, transformational, or anthropomorphic reasoning. In both contexts, J has a strong understanding of the survival advantage of the mute trait. However, in the former context, alternative conceptions are present in his explanation. In the latter context, he displays a populationist idea of change in relative frequency of traits as well as the idea of inheritance.

Next the interviewer asks J to predict what he thinks the crickets on the island will look like five generations later.

> J: Ok, multiply this [points to mute crickets in Gen 2] by four. Eight by four is 32.
> I: We don't even have that many crickets but I think, so we're gonna pretend like there are 32 [ridge-less] crickets.
> J: And this one [referring to Generation 2] would be minus [pause] umm this one [points mute in Gen 2] would be eight, 16, 24, so this [points to chirping cricket in Gen 2] minus 16, [starts counting chirping crickets in Generation 2]. One, two, three, four, so this 16 [places hand over group of chirping crickets in generation 2] wouldn't be here anymore, so there would be more of these ones [points to mute crickets in Gen 2].
> I: Oh so there would be a lot of these [points to mute crickets]?
> J: Yeah, there will be even more than crickets than they ever were.

It is unclear why J chooses specifically to multiply the number of mute crickets in generation two by the number four and to subtract the number of chirping crickets in generation two by 16. But if the formulas of his math are cryptic, their direction is clear. By choosing in his prediction for the next five generations to increase the number of mute crickets to 32 and to decrease the number of chirping crickets to less than zero [14 chirping crickets in Generation 2 minus 16 equals minus two], J reveals his understanding of the survival and reproductive advantage of the "ridge-less" trait and how it translates into cumulative changes in the proportion of traits over multiple generations. As in the previous episode, J avoids using teleological, anthropomorphic, and transformational language in this context of predicting and explaining change on a population level.

In the next task, the interviewer sets up the problem by showing J a template of a pool with guppies in it. The interviewer asks J if he notices anything about the guppies in the pool. J points out that a lot of the guppies in the pool are bright and colorful (i.e., 12) and a few are gray and camouflage with the rocks in the pool (i.e., four). The interviewer introduces the environmental press by placing predator fish icons on the pool template and tells J that predator fishes came into this pool one day and began to eat the guppies. The interviewer then asks J what he thinks the pool of guppies will look like one generation later.

> J: [Counts the number of guppies in generation 1] There's four more see-through guppies and four less non-see-through-bright colorful guppies.
> I: How would that happen?
> J: Just like the other one, these ones [points to a gray guppy] would multiply by two and because there's four more of them there should be four less of these [points to a colorful guppy].

J refers to his previous ideas as he explains, "just like the other one [cricket task]." His prediction shows a shift in the distribution between colorful and gray guppies. He again explains how the individuals with the advantageous trait will "multiply by two" while the ones with the disadvantageous trait will decrease in number. His explanation displays an understanding of the survival and reproductive advantage of being a "see-through" guppy and its effect on the distribution of traits in the population. We should note that again in this episode J does not express any alternative conceptions nor does he use the term "evolution" to explain change.

In the context of explaining "what the scientist saw," J employs the term "evolve" and the "need as a rationale for change" heuristic. The interviewer then shows J what the scientist actually saw. She lays down a template of the pool of guppies and explains to J that this is what the scientist saw when he came back to the pool one generation later. On the template there are 10 gray camouflaged guppies and six bright guppies. The interviewer asks J to explain how these guppies in the second generation differ from the ones in the pool in the first generation.

J: [Counts the colorful guppies] There's three less. And [counts the gray guppies] so they got more. There's seven more this time and seven less.
I: That's close to your prediction, so how do you think that happened?
J: *They've evolved, so they can survive* [emphasis added].
I: They evolve so they can survive?
J: Mmmhmm.
I: Tell me more about how they evolved.
J: *Well they evolve when these guys* [points to predator fish] *started to come in because they wouldn't survive if they were all colorful* [emphasis added].
I: They wouldn't survive if they were all colorful? Is that what you said?
J: Ya, they're more likely to survive if they were kind of like the color of the rocks in the water.

In this episode, we see for the first time J using the term "evolve" in the context to explain change in a population over one generation. He evokes a teleological conception when he explains that "they've evolved, so they can survive." He further explains the guppies' directed drive to survive after the predator fish arrived "because they wouldn't survive if they were all colorful." Based on this context and those of the prior episodes, we see that J expresses different conceptions in different contexts. In some instances, J's explanations display a close approximation to the process of natural selection. And in other instances his explanations combine the term "evolution" with teleological language. J evokes the term "evolution" when he does not generate a mechanistic explanation of change.

In the context of predicting the population for the next three generations J adheres to the "mating and multiplying" strategy. When the interviewer asks J to predict what the next three generations of guppies will look like, he abandons his teleological reasoning (and "evolution") and resumes his computations.

J: 21 see-through guppies and 21-7, 21-5.
I: I'll keep track of the math for you, 21-5 is 17.
J: So it'll be negative 17 colorful ones.
I: Negative 17 colorful ones and 21, and how would that happen?
J: Cause there's seven more here [points to the gray guppies in Gen 2] and 7 times 3 equals 21, and 7 times 3 21 and 5 minus 21 equals 17, no negative 17, so 21 [inaudible] 17 [sic].
I: So you think they'll be a lot of see-through ones, 21 see-through ones, negative 17 colorful ones.
J: Yeah.
I: Why did you make it so that there were more see-though ones?

J: Because if they're surviving they'd be see-through because and there would be less of these guys [colorful guppies] because these guys [predator fish] would be eating them.

In his prediction for the following three generations, J arrives at the number of gray, "see-through" guppies by multiplying the number of gray guppies in the second generation (seven) by the number of generations later (three). He subtracts five from 21 and arrives at negative 17 colorful guppies for the next three generations (prompted by the interviewer's misguided aid in arithmetic: 21-5=16). The logic behind subtracting certain numbers is unclear. However his prediction reveals an understanding of the survival advantage of the gray, see-through trait. In this context of prediction, J explains the change on the population level, "Because if they're surviving they'd be see-through because and there would be less of these guys [colorful guppies] because these guys [predator fish] would be eating them."

J coalesces the term "evolve," with the "need as a rationale for change" and the "mating and multiplying" heuristic to predict and explain change in population. Beginning a new task, the interviewer shows J a set of templates with banded-peacock butterflies on them. When the interviewer asks J if he notices anything about these butterflies, he points out that eight of the butterflies have green stripes on them and two are plain black. The environmental press is introduced when the interviewer lays down two bird templates and tells J that these birds came to the place where the butterflies live and scientists have noticed that the birds seem to attack only the butterflies with green-striped wings. The interviewer then asks J what he thinks the butterflies that live there will look like 50 generations later. The interviewer lays out four templates for J to choose from. The first template shows the butterflies just the same as the first generation, with eight striped butterflies and two plain black butterflies. The second template shows them half striped (five) and half plain (five). The third template shows two striped butterflies and eight plain butterflies. The fourth template shows all 10 plain black butterflies. The interviewer asks if one of these pictures show what he thinks the butterflies will look like 50 generations later. J responds.

J: [Picks up fourth template] *They evolved again* [emphasis added].
I: Tell me what you think evolved again means because that's a complex word.
J: *Well these guys* [points to birds] *got these guys* [points to green butterflies in template 1] *and they die off and these guys* [points to black butterflies] *made babies and there were more and more* [emphasis added].
I: And what about these [points to black butterflies]?
J: *They mated and multiplied* [emphasis added]. They couldn't get this one [points to template 1] because this one is that one [points to original generation 1 template], they did not get this one [points to template 2] but they couldn't have gotten this one [points to template 3], they could've gotten this one [picks up template 4].

In prior episodes, J either gives a near natural selection explanation or he uses the term evolution to explain change in tandem with teleological language devoid of the mechanistic process. In this episode, we witness for the first time the combination of J's use of the term evolution in conjunction with a near natural selection explanation of change. Of note is the fact that J does not use teleological language to explain change here. When J says "they evolved again," the "again" is his referral to the process that he sees as a recurring explanation for the phenomena across the tasks. When asked what "evolved" means, J explains the survival risk of being striped, as those butterflies get attacked and die off. He further explains the survival and reproductive advantage of being plain black, for those that don't get attacked can make babies. He further explains the shift in relative frequency in the population when he goes on to say that "there were more and more [plain butterflies]."

Seeing that J has generated a near natural selection explanation, the interviewer deliberately skips the dynamic assessment portion in this task and goes straight to the "revoicing" episode. In this part of the task, the interviewer reads to J "what another student said," which is the natural selection explanation to the butterfly problem. The interviewer then asks J what this student meant.

> J: MmHmm [nods].
> I: What do you think the kid meant?
> J: [Picks up template 4] *That they'll evolve* [emphasis added]. And these guys [points to striped butterflies] will not [inaudible] anymore.
> I: Do you think that kid was right or wrong?
> J: Right.
> I: Why do you think he was right?
> J: *Because these guys* [points to black butterflies in original template] *would need to evolve that to do what he said to mate, and these guys* [points to striped butterflies in original template] *need to evolve too but they won't be able to, only their babies can be evolutions, but they* [points to striped butterflies] *couldn't be, so they would die, and there'd be less of them, and there would be even more* [black butterflies] [emphasis added].

In his explanation as to why he thinks this student is correct, J uses teleological language when he reasons that the black butterflies in the first generation "need to evolve." The meaning of the word "evolve" becomes more equivocal when he says "they would need to evolve to...mate." To J "evolve" may mean to survive long enough to reproduce. He points to the striped butterflies and says, "They need to evolve too but they won't be able to, only their babies can be evolutions, but they [striped butterflies] couldn't be." Here J reasons that the striped butterflies in generation one "won't be able to" evolve, yet "their babies can be evolutions." J's explanation is open to multiple interpretations. One interpretation is that J harbors a transformational conception and believes that the babies of the striped butterflies can evolve because their characteristics will be different from their parents and thus be more suited to their environment. Another interpretation is that J is suggesting the babies of that whole population of butterflies will "evolve" resulting in more of those individuals with the advantageous trait in future generations. In either interpretation the teleological slant is clear: the butterflies will "evolve" because they need to.

In the preceding contexts within-kind variation is foregrounded into the stem of each task, and J's responses grow progressively more sophisticated. In the contexts that follow—the sparrow, cheetah and desert plant tasks—no such foregrounding occurs. The shift in emphasis from micro-evolutionary phenomena within distinct time frames to less quantifiable, longer-term change appears to disrupt J's pattern of reasoning. He again cites evolution to explain generational change, and his use of the word becomes more ambiguous.

J employs the term "evolve" and the "need as a rationale for change" heuristic to explain change over time.

Sparrow task. In the sparrow task, the interviewer tells J about a type of bird called the House Sparrow, which was brought to the United States 100 years ago. She shows J a template with six House Sparrows of varying sizes, some large, some small. She then shows J a template of what the House Sparrows of today look like in cold places. There is a noticeable difference in size: sparrows that live in cold places today are bigger than the sparrows of 100 years ago. The interviewer then shows J a template of House Sparrows that live in warm places today. In this template, it is noticeable that the sparrows that live in warm places are smaller than those that lived there a hundred years ago. The interviewer then asks J how come the birds that live in cold places today are so much bigger than the ones from a hundred years ago.

> J: *Evolution* [emphasis added].
> I: Evolution. Tell me what you mean by evolution, because that's a really hard word that most people don't understand.
> J: I think this first and now it's both [inaudible].
> I: What was that?
> J: *I think these guys* [picks up 100 years ago template] *first live* [inaudible] *in a little of warm, warm and cold, some of them are small and some of them are big* [referring to the varied sizes in 100 years ago template]. *But when it's colder* [points to cold places template] *and they need to get bigger* [emphasis added]. And most part there's other one too and it got like this [points to a sparrow in cold places template]. It got like and then there isn't any just like this [points to 100 years ago template]. This one is small [points to warm places template] and this one is a little bigger [points to cold places template]. A hotter climate [points to warm places] and colder climate [points to cold places].

When asked to explain what he means by evolution, J asserts that "when it's colder" the House Sparrows "need to get bigger." He does not provide an explanation as to how the size of the sparrows changed. He simply reasons that the sparrows "got like this" as he points to the bigger sparrows in the colder climates and "there isn't any just like this" as he points to the sparrows from a hundred years ago.

This is the first episode in which J does not articulate the survival advantage of a trait and its affect on the distribution of traits in the population. The change in J's reasoning may be attributed to the change in context of the sparrow task, which differs from the earlier tasks. Here J is asked to explain change over a long period of time as opposed to generating a prediction for what the population will look like over one or several generations. This task also does not have icons for J to manipulate and use as an object of thought nor does it lend itself to the mathematical solutions he devised for the preceding items.

In the dynamic assessment portion of the sparrow task, the interviewer gives J a hint about the survival advantage of a larger body size combined with the idea that sparrows inherit their body size from their parents. The interviewer then asks the original question again, how come sparrows living in cold climates today are so much bigger than the ones from 100 years ago and J answers, "*They got their body size from where their parents' climate was. They will get as big as they need to be in their parents' climates* [emphasis added]."

J appropriates the idea of inheritance. However, he sees the offspring's body size being determined not by the actual size of the parent but rather by the environment of the parent. J's explanation has a transformational tone to it as he reasons that the size of the birds will increase to the extent necessary to survive in their climate. Thus, each generation will become more suited to its environment.

The interviewer next tells J "what another student said," which is the natural selection explanation to the problem. She then asks J what he thinks this student's explanation meant.

> J: MmmHmm. That they get their bones from their parents and survive. Because they wouldn't survive if their parents didn't survive.
> I: Do you think this kid was right or wrong?
> J: Right.
> I: Why do you think he was right?
> J: *Because these guys* [points to cold places] *need to get warmer and these guys* [points to warm places] *don't have to get much heat they would die* [emphasis added].

J's argument, "Because they [the offspring] wouldn't survive if their parents didn't survive," shows an understanding of the survival and reproductive advantage of being big enough to live to reproductive maturity. J agrees with and understands the inheritance portion of the explanation to the extent that "they get their bones from their parents and survive." These fragments of normative reasoning, however, are overshadowed by the broad vein of teleological thought that runs consistently through all of J's answers in the House Sparrow task. That vein is also present in the task that follows.

Cheetah task. In this item, the interviewer shows J photos of cheetahs running. She tells him that cheetahs today can run up to 65 mph, but scientists know that cheetahs that lived thousands of years ago could only run 20 mph. She asks J why he thinks cheetahs today can run so much faster than their ancestors.

> J: *Because of evolution because they, their prey ran fast and they needed to run fast to catch the prey. They needed, they evolved into getting speedier because their prey is speedy to get away from them so they need to get speedy too so they can get them* [emphasis added].

Here J expresses a teleological idea that the cheetahs "evolved in getting speedier because their prey is speedy" and because "their prey ran fast and they needed to run fast to catch the prey." J has an understanding of the advantage of being fast and uses teleological language in tandem with the word evolution to explain the change in cheetahs' running speed over a long period of time. Again in this context, where J is asked to explain long-term change, he does not articulate the same ideas that he expressed in earlier tasks. He makes no connection between the individual survival advantage of running fast and the distribution of traits in subsequent generations.

Desert plant task. In the final task of his pretest, the interviewer shows J pictures of three desert plants and points out how each plant's structure confers survival advantage. The interviewer then asks J to explain how come plants fit so well where they live.

> J: *Evolution* [emphasis added].
> I: [Probes]

J: *Well they needed to survive so the animals want to catch them and they can get the water, so they evolved and got the spikes, got their shapes and sizes to catch the water* [emphasis added].

Asked to explain how organisms have come to be so well adapted to their environment, J again evokes the term evolution. His response appears teleological when he says, “They needed to survive...so they evolved and got the spikes.” His expressed idea also hints at a transformational explanation of change as opposed to a natural selection explanation.

Summary of J’s Pretest

What are the alternative conceptions that J has about evolution? In J’s pretest responses we see a predominance of teleological explanations along with a number of anthropomorphic and transformational ideas. J applies teleological reasoning in varying degrees to many tasks in the interview—most emphatically when using the word “evolution.” We can infer from his reasoning in many of his answers that J understands the concept as a needs-based process: species “evolve” in response to biological imperatives. Throughout the interview we see that his idea of the mechanism of “evolution” is inconsistent. For instance, he argues in the *Brassica rapa* task that the “the seeds would evolve to stand up to the flies.” However, in the butterfly task, he posits that “only the babies can be evolutions.”

How variable or consistent are J’s alternative conceptions across the range of tasks in his interview? And to what extent can the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in his explanations across contexts? Throughout his pretest, J displays a wide range of both normative and alternative conceptions. His ideas shift and vary depending on the context of the assessment task. In the *Brassica rapa* episodes, J uses the term evolution to express transformational, teleological and anthropomorphic ideas. However, we see a significant shift in the cricket and guppy episodes as J expresses scientific explanations and avoids invoking any alternative conceptions as well as the term evolution. In J’s first response to the butterfly task, we witness the coalescence of both the term evolution and a near natural selection explanation. However in the last episodes of the test, where the structure of the tasks involves generating an explanation of change and does not foreground variation in the stem of the task, his explanations are more non-normative, and he expresses teleological reasoning in the last two episodes.

An overall analysis of J’s pretest reveals how his responses are highly context-dependent. Early in the interview, he begins to generate near natural selection explanations in contexts that foreground variation in the stem of the task. These contexts, calling for numerical predictions and utilizing visual aids, induce J to apply mathematical calculations in formulating his responses. As we have seen, the rationale for these calculations is sometimes unclear, but J’s structured approach to working out an answer suggests a receptiveness to progressive reasoning that is, in fact, borne out by the increasing sophistication of his explanations.

That structured approach—and the attendant sophistication—elude him in the later tasks. His conceptions become more non-normative in those contexts that do not foreground the idea of variation and ask of him to generate an explanation for change over a long period of time. Of interest here is his repeated use of the word evolution and the growing amorphousness of its definition. His initial answers to the last three tasks of the test (sparrow, cheetah, desert plants) all make use of the word in ways that suggest a catch-all. As the contexts call for more abstract reasoning J deploys the term almost defensively and when prodded for an explanation asserts a strongly teleological bias.

J's Posttest: Tracking the Effects of Instructional Intervention

As we have seen from the cumulative results of this study, 64% of the 2010 Botany students voiced transformational conceptions in their pretest interviews, a figure that dropped to 29% in the posttest responses. Of the 9% who gave teleological answers in their pretest, 3% gave such an answer after the instructional intervention. J's posttest responses exemplify these trends, as they show a sharp decline in transformational and teleological reasoning.

J Articulates a Near Natural Selection Explanation in Tasks Foregrounding Variation.

Brassica rapa *task*. Returning in his posttest to the *Brassica rapa* task, J again predicts what he thinks the plants will look like one generation after the arrival of the caterpillars.

> J: Well there will be more hairy ones because not very much of the smooth ones would survive because the caterpillars like the smooth ones better than the hairy ones. So if this was the amount maybe there may be even more, but if there was just a batch, then it could be like [points to Gen 2 template], six non-hairy ones, and four hairy ones.
> I: So how would that happen again?
> J: Well the caterpillars like the smooth ones. So they would eat the smooth ones and there'll be not very much smooth ones anymore. The caterpillars don't seem to like the hairy ones so they don't eat the hairy ones.

The interviewer then asks J for his prediction another five generations later. She asks if he thinks the field will look different or the same from the field in the second generation.

> J: Different.
> I: And why do you think it'll be different?
> J: Because they'll be a lot more hairy ones and like almost none smooth ones.
> I: Okay, and how do you think that'll happen?
> J: Well because of five generations, these guys [points to caterpillars] would be eating these guys [points to smooth ones] so they shouldn't be any more of these because that's a lot of generations.
> I: Can you tell me more about that?
> J: Well it's kind of like you multiply this one [points to four hairy plant templates] by two five times. So this eight times two again is 16 times two is 32. So what's that? How much was that?
> I: 32 times two?
> J: One, two, three, four, so I need one more times two again, so it's 64 of the hairy ones and negative something of the non-hairy ones.
> I: So is there anything else you can tell me about that. How you think that would happen?
> J: Well the caterpillars eat these guys [points to smooth plant icons] and not these guys [points to hairy plant icons] because they don't like the hairs. So they only eat these guys [points to smooth plant icons] so these guys might go extinct. But these guys [points to hairy plant icons] but the caterpillars they hate these guys so they'll be plenty full of these guys, unless there's a different kind of insect or animal eating it.

In contrast to his pretest, J shows a clear understanding of natural selection in this task. He introduces a new idea: He distinguishes between a population versus a sample when he says, "So if this was the amount maybe there may be even more, but if there was just a batch, then it could be like [points to the Gen 2 template], six non-hairy ones, and four hairy ones."
J expresses the survival advantage of being a hairy plant in his prediction and explains the apparent change in the distribution of relative frequency. His use of multiplication in arriving at the number of hairy plants for his prediction was explained in a prior pretest episode, when he stated that they "mated and multiplied." He subtracts a number of smooth *Brassica rapa* plants in both the second- and seventh-generation prediction because "they [the caterpillars] only eat these guys [the smooth *Brassica rapa* plants]." His explanation reveals a clear conceptual understanding of generation, offspring and inheritance. In his response in the pretest for this task, J used the term evolution to express both transformational and anthropomorphic conceptions. Here in his posttest, his language is free of teleological, anthropomorphic, or transformational reasoning. He does not use the term evolution in his explanation. He instead applies the concept of natural selection.

Guppy task. Returning next to the guppy task, J makes his prediction of what the next generation of guppies will look like after the predator fish have arrived. Before he lays out any guppies on the template, he voices his prediction to the interviewer.

> J: It might be 12 because there's three guppies, no if there was three predator fish and this amount [gestures to whole pool of guppies in first generation], then there would be like 12 of these see-throughs and then you subtract like, so there's two, eight, minus the colored ones. And there's one, two, three...13. And there'd be only of the colorful one left.

J then lays out 12 camouflaged guppies and one colorful guppy.

> J: There won't be much of these left [points to colorful fish in generation 1] cause like there's only one colorful fish left and 12 of see-through.
> I: Tell me how these guppies [points to Gen 2 template] are different from the ones that lived in the pool before the predators got there.
> J: Well they're see-through and the ones aren't really see-through and the ones are colorful.
> I: I want to make sure that I understand your idea, what do you have here?
> J: Well there's 12 see-through fish and one colorful fish.
> I: How would that happen?
> J: Well there's these guys [points to predator fishes] so I multiplied these guys [the colorful guppies] by three, and I subtracted these guys [points to colorful fish] by eight so that's 12 subtracts four. I subtract eight so there shouldn't be one of these guys [points to the one colorful in Gen 2], there should actually be about five of these guys [lays down four more colorful guppies].
> I: So how did that happen?
> J: Well they couldn't live two generations because that would be considered next generation. But these guys [the colorful guppies] won't really survive because of these guys [the predator fish]. But these guys [the gray guppies] could survive because they like the rocks because they can see through them. And there's three of these guys [points

to predator fish] so I multiplied three of these guys [points to gray fish]. And I subtract eight because that's um 12 minus four.

When the interviewer shows J "what the scientist actually saw," J explains the difference between the first and second generation of guppies.

J: Well they subtract nine of the colorful ones and add 13 of the see-through ones.
I: How did that happen?
J: Well these guys got more, because each one, each guppy has more than itself.
I: More than itself?
J: Ya more kids than self, so more see-through ones, 'cause these guys [points to colorful guppy] got eaten. And they inherit what they look like from their parents, so and they multiply because they couldn't survive, the colorful ones.

The interviewer asks J to predict what the following three generations of guppies will look like.

J: Negative 23 of the colorful ones.
I: Show me what you think.
J: 23 plus like 13 times three equals 39, so there'll be 39 plus 23
I: I don't think we have enough guppies for that. 39 plus 23 equals 60-something.
J: I'll just put a bunch of these guys [lays down all gray guppies]. And I don't think now, if it were one generation later, there'll be none of these guys [points to predator fish].
I: How are these guppies different from the ones in the pool three generations earlier?
J: Well there were four colorful ones and now there are none colorful ones.
I: How did that happen?
J: Well the guppies ate the fish.
I: The guppies ate the fish?
J: No the fish ate the guppies. And the colorful guppies couldn't survive because these guys [points to predator fish] were maybe too quick for them, and these guys knew where these guys were because they were colorful. And I think before the predator fish came, the ones that had a survival advantage were the colorful ones cause they can find a mate more easily.
I: Just tell me again, what do you have here then?
J: Well, there's lots and lots of the see-through ones because maybe one of the see-through ones got eaten by these guys [points to predator fish] but it shouldn't be that much.

J's explanation for his prediction in this task is similar to his answer in the *Brassica rapa* task. He expresses the idea of how being "see-through" would confer a survival advantage, explaining how "there won't be much of [the colorful guppies] left cause like there's only one colorful fish left and 12 of see-through."

J articulates a natural selection explanation in his prediction for the following three generations of guppies in the pool. In the context of explaining the empirical feedback he makes explicit his understanding of generation, offspring and inheritance: "each guppy has more than itself...Ya more kids than self, so more see-through ones, cause these guys [points to colorful guppy] got eaten. And they inherit what they look like from their parents, so and they multiply because they couldn't survive, the colorful ones." J goes on to further explain how before the arrival of the predator fish "the ones that had a survival advantage were the colorful ones," because "they can find a mate more easily." J shows an ability to draw up hypothetical situations and apply his understanding of how changes in the environment would lead to changes in the survival and reproductive value of certain traits.

Butterfly task. Revisiting next the butterfly task, J predicts what the butterflies will look like 50 generations after the birds that attack them arrive.

> J: Maybe this one [points to third template] or this one [points to fourth template].
> I: How do think that'll happen?
> J: Well these guys [points to striped butterflies] can't fly if their wings are hurting so they would fall, but these guys won't get attacked by the birds so they wouldn't fall, they would survive and pass that on to their children and their children inherit that.

In this episode J chooses the third template, which displays eight black-winged butterflies and two striped-winged butterflies. This template is the mirror opposite in distribution of traits to the original template (i.e., the original template displays eight striped-winged butterflies and two black-winged butterflies). His prediction of a shift in distribution of traits makes explicit his understanding of the core concepts underpinning evolution. His answer reveals his understanding of the survival and reproductive advantage the black wing trait confers and its effect on the prevalence of that trait in the subsequent 50 generations. We should note that although J has applied the mechanism of natural selection in his explanation, he does not bring up the word "evolution" itself.

J employs the term "evolve" and the "need as a rationale for change" heuristic in the context of explaining change over time.

House sparrow task. Turning next to the previously problematic sparrows, the interviewer asks J how he thinks the size of the sparrows has changed over 100 years.

> J: Well because they needed to stay warmer than they used to be, they needed to grow bigger so they can store more heat. *They needed to grow warm, they evolved when they went to a colder place, they inherit the size from their parents but usually it isn't the same size* [emphasis added]. Usually it's just a matter of speaking, like if they have big parents they grow big. *So they might grow bigger* [emphasis added] but they just inherit BIG from their parents, not like their size...
> I: [Probes] Big like their parents?
> J: Yeah, but they're not usually the same size, because nothing is exactly like the same size.

In this episode J brings up the word evolved for the first time in his posttest. Along with the reappearance of the word, the teleological and transformational language returns when he explains, "They needed to grow warm, they evolved when they went to a colder place, they inherit the size from their parents but usually it isn't the same size. Usually it's just a matter of speaking, like if they have big parents they grow big. So they might grow bigger but they just inherit BIG from their parents, not like their size." One interpretation of his explanation is that offspring inherit "big-ness" from their parents, which, according to J, means that "they might grow bigger" than their parents. His concept of inheritance here is more aligned with the idea of "soft inheritance," which allows room for growth and change from parent to offspring. This could be attributed to the fact that the instructional intervention does not include any teaching on genetics. His expressed idea of inheritance deviates from the concept of natural selection and invites a subtle transformational reasoning.

The interviewer offers J a hint about the survival advantage of being bigger in cold climates. She then asks J the original question: How come the sparrows living in cold places today are so much bigger than those from 100 years ago?

> J: It's not like I know very much, but I just know they might have needed to, so they did. But it had to happen in a different generation, or it wouldn't have worked, because they just can't just like grow big and then like small [points to 100 years ago]. They'll grow big [points cold places] but it's in a different, it's 100 years ago and it's today. *So they might have evolved because they got their size from their parents but they might have needed to grow bigger* [emphasis added].
> I: So how did that happen?
> J: I don't really know.
> J: *Well they might have gotten warmer cause in a different place, and they knew how to grow bigger, but then I don't really know how* [emphasis added].

In this context, J admits that he "doesn't know how" the sparrows have gotten bigger. He "just knows that they might have needed to so they did." He puts forth pieces of information. He knows that the change "had to happen in a different generation." He says, "They might have evolved." In the same utterance he voices several ideas. He claims, "They got their size from their parents but they might have needed to grow bigger." He later asserts that the sparrows "knew how to grow bigger" in a different place. J harbors the idea that the population will adapt to its environment and over time the sparrows will be larger. However, in this context, which does not foreground within-kind variation, he has a difficult time aligning his ideas to articulate a mechanistic explanation of change.

The interviewer scaffolds the idea of inheritance along with the survival and reproductive advantage of being big in cold climates. She then asks J the original question.

> J: *Well cause they went into a colder place, they evolved* [emphasis added].
> I: They evolved?
> J: *Cause the bigger guys of the bigger guys evolved, kind of, to here* [points to cold places] *'cause their kids sometimes can be bigger* [emphasis added].
> I: Ok, [probes] they evolved?
> J: *Yeah they evolved because by like nature choosing, like the biggest guys evolve into big guys so small guys might not really survive* [emphasis added].
> I: Okay, so the small don't survive?
> J: And the small ones go to other places and the big ones go to cold places.

In this exchange, J invokes the term "evolve" in tandem with the idea of "nature choosing." J argues that, "The biggest guys evolve into big guys so small guys might not really survive." J believes that "the biggest sparrows" will survive. Yet we don't know what he means by "the biggest guys evolve into big guys." A literal interpretation would suggest that the biggest sparrows grew larger themselves. Another interpretation is that the population of sparrows will bear offspring that will be larger in body size and the change in size occurs over many generations.

Presented again with "what another student said," J provides his interpretation.

> J: *Well that they evolved* [emphasis added].
> I: Tell me what you mean by that.
> J: *Well like, if a sheep came to a BR field, then the shorter ones will have a better chance of surviving and the big ones won't survive, enough to get their plant pollinated, but they might, but it might still get killed. So the small ones evolved and became bigger because they had a better chance of surviving than being small* [emphasis added].
> I: Do you think this kid is right or wrong?
> J: Right.
> I: Why?
> J: *Well because if they evolved, because it was warmer, colder, to be bigger, because they won't survive without that* [emphasis added].
> I: Okay, and then what would happen?
> J: *They would actually grow bigger because they might have needed to, to survive, better* [emphasis added].

In revoicing the natural selection explanation, J offers a teleological response, describing how the sparrows got bigger in order to survive. He recalls a lesson that was taught in the botany instructional intervention. He draws an analogy to the shorter *Brassica rapa* plants having a better chance to survive after the arrival of sheep in the field, but doesn't explain the causal mechanism for change. He relates how in both cases a change in the environment increased the survivability of the organism with the more advantageous trait "so the small ones [sparrows] evolved and became bigger because they had a better chance of surviving than being small." After the interviewer's probe, J explains how they would get bigger, "They would actually grow bigger because they might have needed to, to survive, better." The language that he uses suggests a transformational and teleological conception of evolution.

Cheetah task. The teleological thinking continues as the interview turns to cheetahs. Reprising the pretest question, the interviewer asks J how come cheetahs today are able to run so much faster than their ancestors.

> J: *Well they evolved just like the other ones, and just like the other ones, their prey might have gotten faster to survive, just like the BR if there was a sheep coming to eat them, instead it's the predator evolving to catch the prey instead of the prey evolving to get away from the predators* [emphasis added].
> I: [Probes]
> J: *Well these survived, they got faster so they can catch their prey, and just like the other ones, they inherit their speed from their parents, but, it only cares about whether they're speedy or not* [emphasis added].
> I: Okay, say that again.
> J*: Like if they're speedy or not. I think their parents were speedy but not very much* [emphasis added].
> I: Okay.

J: *And these guys were speedy, these guys evolved to go faster to catch their prey* [emphasis added].
I: They evolved?
J: Yeah
I: Tell me more about that.
J: Well they got this fast because it was over thousands of years. And their prey got fast too, so they can run away from them. But that doesn't mean these guys [points to cheetahs] can't catch these [points to gazelle]. And these guys are fast 'cause if they weren't fast they wouldn't be able to catch their prey.
I: Oh. Okay.
J: But if they were to be catch and they didn't, weren't quick enough, then these guys [points to gazelle] would stab them with their horns and there was that.
I: Could you, if you were to explain that to another kid, how would you do that?
J: *They evolved to go faster* [emphasis added].
I: You think another kid would just understand that?
J: Yeah.

J relates the case of the cheetahs to the prior cases he provided explanations for as he asserts, "just like the other ones." However, we are not certain to which specific cases he is referring. Does he mean those in which he had a clear explanation of natural selection or those in which he expressed alternative conceptions or both? He draws a comparison between the case of the cheetahs and the case of the *Brassica rapa* plants. The latter is a case of adaptive evolutionary phenomena that he learned from class (i.e., *Brassica Rapa* plants and the sheep as an environmental press). He distinguishes how in the *Brassica rapa* case, the prey are the ones "evolving to survive." Whereas in the case of the cheetah, the predators are the ones evolving to survive.

The next line is difficult to interpret. J asserts, "They inherit their speed from their parents, but, it only cares about whether they're speedy or not...like if they're speedy or not. I think their parents were speedy but not very much." One interpretation is that speedy vs. non-speedy is a trait that matters for the survival of cheetahs. He believes that the parents of the offspring that survived were "speedy but not very much" and "these guys [the offspring] were speedy, these guys evolved to go faster to catch their prey." We could relate this to his explanation for the case of the House Sparrow, where "they [the offspring] inherit the size from their parents but usually it isn't the same size. Usually it's just a matter of speaking, like if they have big parents they grow big. So they might grow [go?] bigger but they just inherit BIG from their parents, not like their size." In the same vein, J might be explaining here that the offspring of the cheetah would inherit the "speedy" trait from their parents and not the actual speed of the parent and therefore would end up being faster than their parents because they "evolved to go faster."

Desert plant task. Finally in the case of the desert plants, the interviewer asks J how come plants fit so well where they live. J answers.

J: *Well because they evolved to be able to survive where they live* [emphasis added].
I: Say that again?
J: *Well because they evolved because they needed to evolve to survive. They're now able to survive where they live* [emphasis added].

I: [Probes]
J: It *means to turn into something to be able to survive where it lives* [emphasis added].
I: It turns into?
J: Yeah.
I: How does that happen?
J: *Well it inherits it well it inherits stuff from its parents, but it can get better where they live because of what happens to it* [emphasis added].
I: Okay, because of what happens to it?
J: *Like if it's in the desert, it's hot and dry, it'll have some adaptations to survive in the desert that'll it'll evolve to* [emphasis added].
I: Uh-huh, and then what happens to it?
J: *It has pinches* [points to desert plant picture] *stuff like that and they do the same thing, and what happens to them goes to their kids, like they die but not really but quick enough to make its seeds, it might be able to make the same one again, but it won't be the same, cause it'll have its own advantage* [emphasis added].

J provides here a teleological argument, "They evolved because they needed to evolve to survive. They're now able to survive where they live." The interviewer probes J to explain what he means by "evolving." He provides her a definition, "It means to turn into something to be able to survive where it lives." The idea of "turning into something" suggests a transformational explanation of change. When the interviewer further probes J to explain how that would happen, J replies, "It inherits stuff from its parents, but it can get better where they live because of what happens to it." The idea that "it can get better because of what happens to it" implies that changes occur in direct response to a press from the environment.

In previous episodes, the possibility that J used transformational and teleological language as shorthand for a natural selection conception was considered. However in this response, we see more evidence for J holding dual conceptions, a transformational conception in tandem with a natural selection conception.

Summary of J's PostTest

How variable or consistent are J's alternative conceptions? As evidenced in both J's pre- and posttest, his explanations about evolutionary phenomena are highly variable. He invokes both normative and alternative ideas even within the scope of a single task. His knowledge structures are not coherent and best described in terms of knowledge in pieces. Early on in his pretest, J explains the process of "evolution" in terms of trasformationism. For example, he reasons that the *Brassica rapa* "seeds would evolve and stand up to the caterpillars by growing hairs." He abandons his transformational conception and employs more normative mechanistic explanations in the tasks thereafter. His most prominent alternative conceptions are teleological and are invoked in tandem with his use of the word "evolution." He invokes this alternative conception throughout his pretest and to a lesser degree in his posttest. Throughout both interviews, J often explains how certain organisms "evolved because they needed to." This heuristic, "need as a rationale for change," is employed in conjunction with both his transformational conceptions as well as his scientific conceptions.

The way in which multiple conceptions are cued further supports diSessa's idea that knowledge structures are fluid and can be constructed on the spot, in direct response to the particular cues of the interview question. In their study of students' conceptions of biological phenomena, Southerland and her associates (2001) identified "the needs as rationale for change" heuristic as a p-prim, which was reflected by the prominence of teleological explanations in students' responses across grade levels. They reasoned that teleologically-based explanations are accessible notions based upon the p-prim of need and can explain biological relationships because they make sense on a deep, intuitive level. This notion that need is a p-prim can explain why J still invokes a teleological explanation even after he has displayed a scientific conception.

How do J's alternative conceptions change or persist after his participation in an instructional course that scaffolds the conceptual underpinnings of evolution? And to what extent can the contexts account for the variability in J's explanations across contexts? In J's posttest, the patterns that emerged from his pretest responses reappear more forcefully—as if the summer course has strengthened both his normative and non-normative conceptions. As in his pretest, J's ideas are highly dependent on the features of the assessment task. From pre- to posttest, his explanations show a greater degree of sophistication in tasks that foreground variation. For example, he successfully articulates a natural selection explanation in the *Brassica rapa*, guppy, and butterfly tasks, integrating the following ideas in his responses: (a) survival advantage of trait, (b) reproductive value of trait, (c) inheritance, and (d) change in distribution of traits in a population. Of note is the fact that J avoids using the term evolution in his explanations for these tasks and returns to his pretest method of employing mathematical formulas to calculate generational change. Similarly, in tasks that do not foreground the idea of variation, such as the sparrow, cheetah, and desert plants items, J reverts to using the term evolution and expresses variations of the teleological and transformational conceptions he debuted in his pretest. For the sparrow task, he maintains that change occurred but has a difficult time explaining how, again relying on teleological language and the term evolution. He does not bring up normative concepts such as the reproductive value of the trait or the change in distribution of traits over time.

J's responses are, in many ways, typical of the 2010 cohort. While his adherence to the patterns that emerge from the study make him a valuable subject for case analysis, his atypical responses, particularly his use of the term "evolution," offer insights into the singular dynamic of his pattern of reasoning. By employing the term in both normative and non-normative explanations, J demonstrates the elusiveness of language in measuring comprehension. From pre- to posttest, J's use of the word evolution declines in parallel to his understanding of natural selection. If we surmise that "evolution" is, for J, an imperfectly understood idea, the summer intervention appears to lead him to a better grasp of its principles, thus freeing him from the crutch of the term itself. We watch as the concept supplants the word.

Chapter 5: The Case of S

"Like a dog and cat marry, so this dog and this cat, their kids will like something it's not like cat and not like dog, it's like a goose…."

Overview

Next we have S, a second-grade student for whom English is a second language. S makes significant progress from her pre- to posttest. She comes into the pretest with almost no understanding of variation, inheritance, survival and reproductive advantage (see Tables 17 and 18). Her early explanations display knowledge of certain concepts, such as the growth and life cycle of organisms, but also reveal a wide range of alternative conceptions. As with many in S's cohort, her pretest answers demonstrate a lack of scientific sophistication so encompassing it undermines her ability to discern what is relevant. Some of her pretest answers do not rise even to the level of common alternative conceptions. They are instead misinterpretations of the problem. For example, when asked what a group of organisms will look like x years or x generations later, S might bypass the point of the question (i.e., to predict and explain the shift in distribution of traits within a population) and concentrate instead on the age of the organisms. In the random and arbitrary quality of their focus, S's first set of responses would seem to support the view that basic principles of evolution are beyond the comprehension of children her age (Lawson & Thompson, 1988). And yet as Kathleen Metz has noted: "[Children's] reasoning concerning natural phenomena about which they have not developed significant interest or familiarity is unlikely to reveal the power of their epistemic capacity." (Metz, 2011, p. 7)

One purpose of this research is to discover how alternative conceptions impede a child's understanding of the underlying principles of evolution and what instructional avenues those conceptions provide for movement to a more normative comprehension. In that context, S's case presents an intriguing model. If a student as untethered to normative conceptions as S appears to be can make progress through participation in a novel instructional intervention (and she *does* make progress), the view that evolutionary studies are beyond the grasp of young children must be called into question.

Table 17.

Pretest Summary of S's Alternative and Normative Conceptions, Sorted by Episode

Pretest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Question
BRASSICA RAPA Prediction and Explanation: one generation after arrival of caterpillars			
BRASSICA RAPA Prediction and Explanation: five generations after arrival of caterpillars			
GUPPY Prediction and Explanation: one generation after arrival of predator fish	1~Anthropomorphism		1~Literal interpretation of what guppies will look like

Pretest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Question
GUPPY Empirical Feedback: How is this different? How do you think that happened?			1~Literal interpretation of what guppies will look like
GUPPY Prediction and Explanation: three generations after arrival of predator fish			1~Literal interpretation of what guppies will look like
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds	1~Anthropomorphism		
BUTTERFLIES Dynamic Assessment: Survival Advantage of Trait	1~Anthropomorphism	1~Change in Distribution	
BUTTERFLIES Dynamic Assessment: Inheritance, Survival and Reproductive Advantage	1~Anthropomorphism	1~Change in Distribution	
BUTTERFLIES Revoicing	1~Anthropomorphism	1~Change in Distribution	
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Teleological		
SPARROWS Dynamic Assessment: Survival Advantage of Trait			
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage	1~External Agent		
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Transformationism 2~External Agent		

Table 18.
Posttest Summary of S's Alternative and Normative Conceptions, Sorted by Episode

Posttest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Question
BRASSICA RAPA Prediction and Explanation: one generation after arrival of caterpillars		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
BRASSICA RAPA Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Change in Distribution	

Posttest Episodes	Alternative Conceptions	Normative Conceptions	Idiosyncratic Interpretation of Question
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Survival Advantage 2~Change in Distribution	
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Change in Distribution	
BUTTERFLIES Dynamic Assessment: Survival Advantage of Trait		1~Survival Advantage 2~Change in Distribution	
BUTTERFLIES Revoicing		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance	
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Transformationism 2~External Agent		
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage	1~Transformationism 2~External Agent	1~Survival Advantage	
SPARROWS Revoicing		1~Survival Advantage	
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Transformationism		

S's Pretest: Unpacking the Alternative Conceptions

Let us begin our examination of S by evaluating her pretest repertoire of understanding. The first three tasks of the interview (*Brassica rapa*, guppy, butterfly), divided into nine items, are designed to assess a child's ability to understand the concepts of within-kind variation, the survival advantage of traits and the impact of that advantage on subsequent generations. In her answers to the nine items, S fails to register any of these concepts.

Advised at the beginning of the *Brassica rapa* exercise that the caterpillars prefer the smooth over the hairy plants, she nonetheless predicts an increase in the smooth plants from two in the present generation to five in the next. When asked how that would happen she explains, "So there will be, grow up to this flowers [points to smooth plants] and have more of these things [points to caterpillars] to eat them."

It is unclear whether S believes that her predicted prevalence of smooth *Brassicae rapae* will come about in response to the needs of the caterpillars or if more caterpillars will arrive because there are more smooth *Brassicae rapae*. Her answer misses the intended subject of the item—the survival advantage of the hairiness trait—and centers on the hungry caterpillars. Asked to extend her prediction forward five generations, S lays down five hairy *Brassicae rapae* on top of the five smooth ones from her previous prediction, explaining, "Because if they have the, because five years ago, this like this [points to Generation 1], so over five years, they will be changing to have some hairs." When asked how that would happen, S is unable to supply an answer, "This really, just, I don't know what reason I can say, it's hard."

S takes the position that the smooth *Brassicae rapae* will change and "have some hairs." Although she was told at the beginning of the task that the caterpillars tend to eat the smooth ones, the proposed change in structure does not elicit further reasoning about the effect of the caterpillars in the population after the plants "grow hair." Her answer appears to be focused on what the plants will look like across their life span. She does not address the original question (i.e., what the plants in the field will look like in the following five generations) and displays no understanding of the concept of generation or the underlying idea of organisms bearing offspring. The traits of smooth and hairy are not variants in her explanation, but rather different stages of structure across the life cycle of all *Brassica rapa* plants.

S employs anthropomorphism to predict a change in population. Similarly in the guppy task, S fails to register the trait variation in color as a significant factor in how the population will change over time. Asked to predict what the pool of guppies will look like one generation later, S expresses an idea of the life cycle of guppies.

> S: One year and a one year, the children will change into the big fish, and some older fish will die and some new fish come like that. Here have more grow up the fishes. Someone of these fishes [points to predator fish] will go back to they live their home to tell another fish they have some new fish, so maybe little bit of this [predator] fish to eat them.

When asked how that would happen S further anthropomorphizes the predator fish by assuming the fish's voice.

> S: Because they have more food, they can eat too much, they don't want to lost that younger beautiful younger fish so they will tell the family, friends to [in a higher pitch] "Hi, I go into their vacation I have more new younger yummy fish, you can come eat with us!" like that.

As in the *Brassica rapa* item, S is not focused on the variation of traits in the task. She offers, instead, a family narrative, where old guppies live out their lives, young guppies grow up and predators plot against them. She repeats a version of this explanation when exposed to the empirical feedback of "what the scientist actually saw," and maintains it still when asked to predict what the following three generations of guppies "will look like." S appears to interpret the prompt literally. She gives a description of the guppies' appearance. She reasons that they will "be older." Her attention is not drawn to the variation in color of the guppies and how it can confer survival advantage. She compares the life cycle of guppies to humans to explain the various ages of the guppies in the pool.

The insistent anthropomorphism of S's responses in the guppy task is repeated in the butterfly context. Asked if one of the four pictures shows what she thinks the banded peacock butterflies will look like 50 years after the birds that attack them arrive, she answers.

> S: None of the picture, no butterflies are there, because 50 years ago, the birds hurt the butterflies, so they know that, some butterflies know the birds will in this year come back, so all of them more will fly away because they don't want the birds to hurt them.

Here again S seems not to register the color variations of the four pictures. She moves outside the framework of the question and rejects all four options. Her answer instead attributes to the butterflies an anthropomorphic ability to act on historical precedent. The butterflies, according to S, "know" that the birds will attack them and all of them will "fly away because they don't want the birds to hurt them."

When the interviewer offers S a hint that the birds mostly attack the butterflies with striped wings, S responds with a question.

> S: Hold on, the birds just eat this one [points to striped-wing butterflies], not eat this one [points to black butterfly]?
> I: [Nods]
> S: Oh okay. So I think this butterfly [points to striped one] because they don't want the birds to hurt them, so they will go away up there. So I think more black butterflies to go on there like this [points to third template].
> I: Like this. So how will that happen?
> S: Because this butterfly [points to striped one in template 3] is too beautiful and they [birds] want to hurt them, they don't want to be, they don't want the birds to hurt them so they don't want to stay here to be the birds to hurt them so they go away just a little bit of butterfly on there. They don't know that maybe they're not to listen not about [inaudible] to say to them that the birds will hurt you, so they stay here.

Here S grasps that the birds seem to attack only the striped-wing butterflies and she predicts that there will be either very few or no striped butterflies left 50 generations later. But she clings to her original concept of butterflies acting on the basis of knowledge and intentionality. She explains that the striped butterflies are "too beautiful" and "they don't want the birds to hurt them, so they [the striped butterflies] don't want to stay here to [have] the birds to hurt them so they go away." She adds that there will be a couple of striped butterflies left, stragglers who "don't know" or didn't "listen" to the warning that "the birds will hurt you, so they stay here."

The interviewer offers another hint in the dynamic assessment part of the interview. She tells S that the butterflies that are most likely to survive will pass on their wing color to their offspring because butterflies inherit their wing color from their parents. She then asks S how might that effect how the butterflies will look 50 generations later.

> S: So they will change, so maybe like this picture [points to template 4].
> I: Like that picture? How will that happen?
> S: Because, I think this is more likely [points to template 4], this and this [points to templates 3 and 4]. This two pictures [templates 3 and 4] are more likely because they in that long years ago they know this butterflies [points to striped in original template] knows that this birds [points to bird] are their hurtners [sic] so they don't want to hurt, so they all fly go away so they [birds] don't need these [black] butterflies so now just all them is black butterflies here.

In this item, S is firmer in her new prediction. She argues that there will be only black-winged butterflies left. Her prediction changes, but her reason does not: The butterflies migrate out of harm's way based on their knowledge of the birds' intentions to hurt them.

When the interviewer tells S what "another student said," which is the natural selection explanation to the phenomena, S evaluates the explanation.

> S: I think that's good, because they don't know that the birds come. There's more of this butterfly [points to striped ones in template 1]. When they know, they're will be changing [waves hand from 2nd to 3rd to 4th template] to all black.
> I: They will be changing?
> S: Yeah, they will be changing so I think that kid is right.

When S waves her hand over templates two through four, it appears as though she is referring to the change in proportion of traits that was shown earlier to her by the interviewer while reading the natural selection explanation of what "another student said." Although S says that she agrees with the natural selection explanation, her interpretation of the progressive change in proportion of black and stripe-winged butterflies differs from the natural selection explanation. The changes in proportion of color, according to S, arise from the spread of knowledge among the striped-wing butterflies that the birds will come to attack them. Her reasoning is that as more striped-wing butterflies "know that the birds [will] come" the striped-wing butterflies will fly away and there will be fewer of them, and thus there will be more black-winged butterflies left.

In their 2001 study of students' biological knowledge structures, Southerland, Abrams, Cummins, and Anzelmo introduced the concept of "spontaneous constructions," the idea that children explaining the natural world devise impromptu scenarios drawn from their experience and intuitive understanding and *not* from any unifying framework of belief. S's responses to the *Brassica rapa*, guppy and butterfly questions seem to illustrate this principle. However, in her fidelity to the key ideas of these constructs—the familial structure of the guppies, the butterflies learning from history—we see, perhaps, a prototype conceptual framework that employs anthropomorphism or personification as analogy. S's alternative framework serves the same purpose in her thinking as would a more normative construct: It gives her a structure on which to build understanding and process the new data provided by the dynamic assessment prompts. Thus she revises her predictions through the various items of the butterfly task, but always within the framework of her central conceit: that the butterflies' population is determined by how effectively they have been informed about the birds' intention to hurt them.

The "personification as analogy" framework also underpins S's explanation of why house sparrows in cold places are bigger than those that first arrived in the United States a hundred years ago.

> S: I don't know this one. Let me think. Because cold. First warm, they don't need to, like too much of the food and the hairs to like that. Just cause they are in cold times they need some hairs they don't have, like cause like people have like the jackets or shirts to warm so in cold places that time so there will be more hair and more food and they be keep warm.

S explains change in terms of the sparrows' response to a need to stay warm in a cold environment. She analogizes a sparrow's need for "hair" to a person's need for "jackets" in order to stay warm.

S introduces the idea of an external agent inducing change. The interviewer scaffolds the idea of survival advantage of a larger body size to S and then asks her to explain how this might affect the change in size of the birds over a hundred years. S reasons, "Because it cold that time so they will be bigger than any birds." When asked how that would happen, S replies, "Because they're bigger. Because in cold times they need to eat more and more food to keep warm, so they will be to be fat little bit some will be bigger and one more is their hair." From her reasoning, it appears that S believes that the change in body size is a result of eating more. It is hard to interpret from her utterance whether S is referring to a change in body size during a lifetime or whether the change is occurring over many generations across a hundred years.

The interviewer then scaffolds the following ideas: the survival and reproductive advantage of a larger body size in a cold climate and the inheritance of traits from parent to offspring. When asked to explain how the body size of the sparrows might change in a hundred years, S provides the interviewer her idea.

> S: So I think this big birds is because like some legs is just like here [points to her wrist] like the hands. Like the snake, like something of their body like that will broken [points to her arm] something, and will have NEW color and NEW body that things like that. I think they can in cold places they will be the hairs cause they can like people help their pets cut their hair right, so maybe the hairs grow longer.

S's answer here compares the body parts of a snake to a human. She explains how their bodies heal after an injury and in turn bring about "new color" and "new body." It is hard to interpret how dramatic the change of "new body" is and whether she believes the essences of organisms can transform into something new and different from their original state. She introduces an external agent, humans, to explain the mechanism of change, reasoning that humans, who "help their pets," can facilitate change by cutting their hair, "so maybe the hairs grow longer." Unlike her answers to the guppy and butterfly items, S's explanations in the sparrow items do not seem grounded in any fixed concept. She seems to grasp at fragmentary thoughts: feathers ("hairs") as jackets against the cold, increased food consumption, the body's ability to heal and regenerate, human intervention. She exhibits both the tentativeness ("I don't know this one. Let me think.") and the shifting explanations that Southerland and her associates (2001) document in their study.

S introduces the idea of transformation in the context of explaining change over time. In the final context of the pretest, the cheetah task, S again provides a non-normative answer, but in this last item we see that S attempts for the first time to provide an explanation for evolutionary change. The interviewer asks S how come cheetahs today are able to run so much faster than their ancestors. S offers a lengthy explanation.

> S: Why now will be run faster because now the science and what is greater and greater and greater and so the animals the power is greater, greater and greater.
> I: Greater and greater? Tell me more about that.
> S: Like in long long ago in the world they don't have peoples, likes some monkeys, like that's people. When I was in China, I read a book, it was about this one. So long long

ago, they don't have the peoples, just have, like some monkeys, that gorillas, like that's peoples, they have tails, but their bodies, like people, so now, year and year and years over, so now we just have, because I think more years ago, like, in this time it's like monkeys people and one more they have tails and more and more that is, changing to peoples, no more tails.

I: And how does that, what about the cheetahs?

S: Cheetahs? I think that. Long long ago, because they are powerful more, more powerful.

I: And how did that happen?

S: Because maybe, that's about science, because science is greater and greater, so they can make it someday.

I: Greater and greater?

S: It's good, and good, and good, like that, up, [gestures an upward motion with her finger] like this. I think like something, like a dog and cat marry, so this dog and this cat, their kids will like something it's not like cat and not like dog, it's like a goose, like that, it's not in the world to have like that. So now like maybe the science and world work together, make something like this, what's that name again?

I: Cheetahs

S: Cheetahs. So they make them to more powerful, I think because science is helping.

In the cheetah task S appears to grasp for the first time the intended focus of the question. Her answers are non-normative, but they do address the idea of evolutionary development. Her constructions here seem marginally less "spontaneous" than those in the preceding tasks, and S herself explains why—she has read a book "about this one." While the ideas S gleaned from her reading appear to be misinterpretations of what we may assume were normative (if greatly simplified) concepts, the significant point is that minimal exposure to the idea of evolution has a noticeable impact on her ability to address a question she correctly perceives as related.

S brings up several common alternative conceptions in explaining the change in cheetahs' running speed over thousands of years. From her viewpoint, science is in some sense the drive behind evolution. S argues that because of science "what is greater and greater and greater and so the animals the power is greater, greater and greater." Her idea relates to what Mayr (1999) describes as a non-Darwinian ideology of finalism. The mechanism here is an all-powerful force that pushes organisms towards the direction of progress. When the interviewer probes S on how the cheetahs would, in her own words, become more "powerful," S replies, "Science is greater and greater, so they can make it someday."

S's explanations also include transformational reasoning. She explains how humans were once monkeys, and the monkeys then "had tails" but "many years over" they "[changed] to people" and "we don't have tails today." S describes how the bodies and essences of monkeys have transformed into humans over time. She gives another example of essence transformation, "If a cat and dog marry, they will have an animal not like cat and not like dog, like a goose." Unlike her previous example of monkeys and humans, S's example of essence-transformation here most likely did not come from the book that she read. We can infer from S's example that her understanding of inheritance is very limited. What is novel in this context of explaining change over a long period of time, as opposed to predicting over a shorter period (such as the context in the *Brassica rapa*, guppy and butterfly tasks), is that S evokes a strong transformational explanation and finalistic idea of animals becoming "greater and greater and greater" towards a goal of perfection.

Summary of Pretest

What are the alternative conceptions that S has about evolution? How variable or consistent are S's alternative conceptions across the range of tasks in her interview? To what extent can the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in her explanations across contexts? Reviewing S's pretest answers we may observe that she holds a collection of alternative conceptions, most prominently anthropomorphism, transformationism and external agency. Her alternative conceptions vary across the set of tasks in the interview. In both the guppy and butterfly tasks, S employs anthropomorphism to explain her prediction for the population. In the last item of the sparrow task, as well as in the cheetah task, S invokes an external agency to explain a transformational change over time. She argues that humans can help the House Sparrows grow bigger and that "science" can make the cheetahs more powerful and therefore able to run faster. With the exception of the butterfly task, a common theme in almost all of the tasks is that S does not attend to the variation of traits within a population and the survival advantage that certain traits confer under an environmental press.

S demonstrates in the cheetah task that, once exposed to a biological concept, she is capable of applying it to other contexts. The book S read on the subject of evolution would hardly have given her a nuanced understanding of natural selection—and indeed her answers in the cheetah task are non-normative. (We can imagine from her reference to people with tails the illustration that would likely have appeared in such a book: the forward-moving line of monkey, ape, Neanderthal and man). What is noteworthy in S's answer, in addition to the misconceptions it evokes, is the fact that she recognizes the cheetah task as related to the book she read and *uses* that recognition to formulate her answer.

S relies heavily on anthropomorphic interpretations and on transformational scenarios. While her thinking may be fairly characterized as "magical"—animals talk to each other, organisms change from one thing to another—it typically adheres to an internal consistency (within each task) to which she returns even in the face of prompts. For example, in the *Brassica rapa* task, she repeats across items her initial idea that the smooth plants will grow hairs. In the guppy task she returns in each response to the concept of the guppy family as a multi-generational entity. Most dramatically in the butterfly item she holds to the notion that butterflies pass on their history and act on that knowledge to avoid future attacks from the birds. Finally, in the cheetah item she expresses forcefully a belief in the progressive nature of organism transformation.

This coherence clearly does not extend across contexts—she does not apply the same reasoning to *Brassicae rapae* and to guppies. Rather, her explanations appear to be constructed on the spot, in direct response to the particular cues of the biological phenomena and the interview questions. Her explanations are what Southerland et al. (2001) would describe as "spontaneous constructions." This idea makes use of diSessa's (1993) "knowledge in pieces" theory in that it sees students generating explanations based upon the p-prims activated by specific characteristics of the phenomena in question. In this context, then, we see not so much that students like S hold poorly constructed, incoherent frameworks of understanding, but that they have no formal, pre-existing framework at all for particular topics, and instead reason spontaneously from core intuitions in effect to erect frameworks tailored to the moment.

In S's pretest responses, then, we see both the dimensions of her alternative conceptions and her potential for improvement. In S's posttests we will see significant changes in the way that she approaches the items involving prediction and explanation over several generations. We will also see how some of her alternative conceptions persist in very particular contexts.

S's Posttest: A Shift Towards Normative Conceptions

In this section we judge the impact of the instruction on the basis of S's posttest answers. And on that basis we may characterize the impact as significant. The effectiveness of the instructional course in grounding S's initially naive thinking on natural phenomena and establishing concepts within which she can evaluate data is immediately apparent in the first item of her posttest. Whereas her pretest responses to the two *Brassica rapa* items missed the point of the exercise entirely, in her posttest she not only understands the question, but gives a scientifically sound answer.

In S's prediction for the next generation of *Brassica rapa* plants, she displays a change in proportion of traits. Whereas the proportion of hairy to smooth plants for the first generation is eight to two, here S lays down five hairy plants and three smooth plants for the second generation. She explains to the interviewer how the smooth trait confers survival advantage.

> S: I want to say here if because the caterpillars they eat this [points to smooth *Brassica rapa* plant], no hairs this one, right? So they will eat so much of this [points to smooth *Brassica rapa* plant] then they can have just a little bit of seeds, this one [smooth]. Then because they [caterpillars] do not eat this hairy one [points to hairy *Brassica rapa*]. This hairy one will stay more.

Looking back to her earlier prediction on this item, we recall that S laid down more smooth plants and reasoned that there would be more caterpillars to eat them. In this context, S lays down five hairy and three smooth *Brassica rapa* plants, displaying a change in proportion of traits after one generation. She explains that the caterpillars will eat the smooth ones and there will be "just a little bit of seeds," and that because the caterpillars don't eat the hairy *Brassica rapa* plants, "the hairy ones will stay more." S shows an understanding of several concepts that were absent in her pretest. She attends to the variation in traits among the *Brassica rapa* plants and her explanation reveals her knowledge of both the survival and reproductive advantage of possessing the hairy trait, as well as how this advantage affects the distribution of traits in the *Brassica rapa* population. In her pretest, S was focused on the changes that occur during the lifetime of a plant. In her posttest, S's ideas span multiple life cycles. She refers to the smooth plants getting eaten and bearing fewer seeds, thus revealing that she also understands the meaning and idea of generation.

In her prediction for the following five generations, S envisions a progressive change in proportion of traits. Laying down seven hairy and one smooth plant, she offers the following explanation.

> S: I think the caterpillars in the years…they will come into the *Brassica rapas* here to eat something the *Brassica rapa* plants right again and again, so I think the *Brassica rapa* no-hairy ones [smooth], one will left just one.

When asked how that would happen, she explains.

> S: Because so much maybe in this years the caterpillars is coming to here to eating so much times right or two or three or like that time. I think they will eat more than before, so I think they won't be left this [points to smooth plant]. I just think maybe it just have something very lucky *Brassica rapa* will left back.

S's explanation here marks a significant shift in reasoning from her pretest. There she laid down five hairy plants on top of the smooth plants that she initially chose for her one-generation-later prediction. In the pretest she believed that the smooth plants would change and grow hair across their lifetime. However, in this posttest item S shows an understanding of the survival and reproductive advantage of possessing the hairy trait. Her prediction and explanation also demonstrate her understanding of accumulative change in proportion of traits over multiple generations.

The next series of questions returns to the guppy item. S explains to the interviewer her prediction for the next generation of guppies after the arrival of the predator fish.

> S: There is just I just think maybe this one, this fishes [points to predator fish] will like the colorful one more, so I just make them like eight more left, then the no-colorful one is five more.

When the interviewer probes for how that would happen, S further explains.

> S: Because I just think this fish [points to predator fish] will like the colorful fish more so I make the left eight more this [colorful] fish then I just then I think because the [predator] fishes some of them will like the no-colorful ones, that one [points to gray fish] more, so I make them more than here [points to generation 1].

S's prediction shows a change in proportion of traits from generation one (original template: 12 yellow guppies, four camouflaged guppies) to generation two (S's prediction: eight yellow guppies, five camouflaged guppies). She reasons that the predator fish will "like the colorful ones" more than the gray ones. Unlike her pretest answers, which were focused on the growth and life cycle of guppies, S's explanation here is centered on the variation in color of the guppies and the survival advantage the drab, gray color confers.

When shown what the actual second generation looks like, S points out the similarity between the empirical feedback and her own prediction, S: "I think I'm right. This [predator] fish like the colorful fish more." Predicting what the following three generations will look like, S selects 13 gray and two yellow guppies.

> S: There is, because three generations is long, because these [predator] fishes are still there, maybe just one or two of this colorful fish is lucky then they just have life in this pool.
> I: How did that happen?
> S: I think that happened because this [predator] fish like the colorful fish more. Then the colorful fish will die faster than the no-colorful fish. Then the no-colorful fish will a generation, then many many generations over, the lucky fish will die too, more many many many many generations.

In this prediction, S shows a continual progression of change in proportion of the colorful versus non-colorful traits to the extent that a shift in relative frequency results. She discusses the survival advantage of being gray or "no-colorful" and the cumulative change over "many, many, many generations." She adds a probabilistic idea that over time even the "lucky" colorful fish will die too.

In her pretest, S made no distinction between the colorful and gray guppies in her prediction and hence there was no mention of survival advantage of a trait. S was focused on the change in age of the guppies over time and she personified the predator fish, mimicking their voices and their interaction among each other. Here in the posttest, S avoids any anthropomorphic ideas. Instead she highlights the survival advantage of being "not-colorful" and its effect on the proportion of traits over multiple generations.

As in the *Brassica rapa* item, the instructional course appears to have pulled S's reasoning into a conceptual framework within which she can calculate biological probabilities. The distance she has traveled from the frequent anthropomorphism of her pretest responses is surely as significant here as her new-found awareness of trait variation and survival advantage.

That distance is not duplicated in the context that follows. Revisiting the question of what impact predator birds will have on the makeup of the butterfly population, S reverts to her original idea of the butterflies escaping through flight. In her prediction of what the butterflies will look like in the next 50 generations, S wavers between choosing the last two templates, "Maybe like this template 3] or like this [template 4], I don't know this two likely."

The third and fourth templates display mostly black butterflies and all black butterflies, respectively. Her explanation echoes the ideas she expressed in her pretest. She reasons that through chance, a few of the striped "beautiful" butterflies will survive.

> S: Some of the beautiful ones is lucky then they have life they live in there but some of them are too scared of the bird and they fly to something to new place so they will be like this [points to template 4].

As she is explaining the probability of some of the beautiful butterflies being lucky and avoiding attack, she vacillates and ultimately chooses the fourth template displaying all black butterflies and says, "They will be like this." As in her pretest, it is hard to interpret whether her prediction is indicative of what is occurring in the same generation or over 50 generations. She refers to the striped butterflies flying away but she does not mention the offspring of the butterflies that remain.

When the interviewer offers a hint about the survival advantage of having plain black wings, S agrees with the statement and adds, "Everyone will knows that happen, it's just it will be the black butterfly will more than the green butterflies." When the interviewer probes for how that would happen, S explains.

> S: I think maybe the butterflies will just fly to another place so that will be just the black butterflies like this one [template 4] but someone really lucky. I don't think it will be like these three pictures I think 50 generations over, I think now I'm changing, I think it will be just like this picture [picks up template 4]. Because this bird is too scary it will kill this butterfly [points to striped] they will kill them and hurt them. I think just the black butterfly stay.

In the middle of her explanation, S changes her mind. She is more certain that the butterflies will be all black, for the striped ones will all "fly to a new place." What is interesting to note is that although her explanation is somewhat similar, her anthropomorphic language is not as dramatic as it was in her pretest.

The interviewer reads to S "what another student said," which is the natural selection explanation. S agrees.

> S: That kid was right. Because there was 50 generations over, because the birds kill the beautiful ones so she said that the many generations over, so they will be just more this uglier ones will stay right there. I think she's right.

In revoicing the natural selection explanation, S abandons anthropomorphic language. The change in proportion of traits is attributed to the die-off of striped butterflies as opposed to them knowing that they need to fly away. The initial tenacity of S's anthropomorphism in this task demonstrates how strongly-held her alternative conception was. That her naïve idea does, in the end, give way, illuminates the epistemic potential of instructional scaffolding. Through the sequence of butterfly questions in S's posttest we may observe the gradual decline of her anthropomorphic assertions. In her first answer she repeats the explanation, though less forcefully, of her pretest: that the butterflies fly from harm. In her second response, after a hint, she wavers, deciding in mid-answer that they cannot elude their predators. In her third answer she gives up the anthropomorphic language entirely. S's progress in this sequence is too tentative to suggest a conclusive replacement of her alternative thinking, but it demonstrates that such a process is achievable.

Coming next to the question of how sparrows have changed in size over a hundred years, S suggests that through the "use" of science, people can change an organism's kind in order to make it more adapted to its environment.

> S: Maybe like the years, maybe someone think this is a real cold place then they miss something. Like I know something like now some of the dogs and cat in long time ago, they are really small or really fat like that. But now they are really skinny and really small. Some of them because some people use science things to make them change their kind. Maybe some nice people think this is a real cold places, these birds are small and they don't have too much hair for their bodies. Then they use something like science like that to help them change their kind, make them bigger.

S echoes one of her pretest answers on this item; explaining the change in body size in terms of help from people, who are responding to the sparrows' needs to stay warm in a cold environment. In her pretest, she asserted that people can cut the hairs [or feathers] of the birds and they would grow back a "new body." Here she expands upon the idea of humans helping in a different manner. She expresses the idea that people can "use something like science to help them change their kind, make them bigger." This explanation also mirrors the response that she gave in the cheetah item of her pretest, where "science is helping" the cheetahs get faster over time.

The interviewer offers S hints related to inheritance, and the survival and reproductive advantage of being bigger in cold climates. S provides the interviewer her idea.

S: I think like maybe some people like help some of the birds is change their kind then a many generations so that birds grow bigger too. Their parents make them bigger.
I: So many generations and bigger parents? Can you say more about that? I think you have some neat ideas here. I want to hear more about that.
S: Ya okay, so I think that in years when some birds got to the cold places, the people think they're cold and they're just too small and very cold. So they let them use the science to change their kind make them bigger so they can survive in the colder places. Then they like one generation one generation one generation over like that. Then the parents the bird will just like their parents, grow bigger.
I: Okay, so they grow bigger?
S: MmHmm.

S further expands upon her idea that through human intervention and the use of science, the sparrows may be bred to grow bigger in order to help them survive in cold climates. She adds that the offspring will, "like their parents, grow bigger." It is hard to interpret from her idea whether she means that the offspring will inherit the parent's acquired trait of bigness or that the offspring will acquire the capacity to grow bigger in their lifetime.

The interviewer then asks S to evaluate what another student said and reads the natural selection explanation to her.

I: This kid said there are bigger house sparrows where it's cold, because they have a better chance of surviving there. The smaller ones were always less likely to survive long enough to pass on their small size to the next generation. In each generation there are fewer of the small ones that got cold and didn't live long enough to mate and have young. Over many generations, the sparrows that lived in the cold got a little bigger and little bigger.
S: How can that happen?
I: What do you think? Do you think that student was right or wrong?
S: I don't know, but I think the first part is right but the last part I'm not sure.
I: The last part? What was that about?
S: The student says the birds just grow bigger and bigger and bigger like that. I'm not sure if this is right or wrong.
I: And the first part you thought that was right?
S: Yeah
I: Why?
S: Because the bird can live in the cold places. If this small bird live in there because if they're small they can't survive too long. I think the student's right.
I: So the little ones can't survive?
S: Too long. So long in the cold place, maybe one week or day's week. I think they can't live in the cold place for a month, but maybe a week or a day maybe they can.

Because of the ambiguous wording in "the other student's explanation," S interprets the natural selection explanation differently than the way it is intended. S agrees with the first part of the explanation that the small sparrows would not be able to survive in the cold environment. However she is uncertain about the last part of the explanation which she interprets as "the birds just grow bigger and bigger and bigger." She asks, "How can that happen?" In the previous item she explains that science can "change [the sparrows'] kind and make them bigger." In evaluating this explanation, she is unsure about the idea that a sparrow can grow bigger on its own. This idea of animals changing their bodies on their own is inconsistent with her own idea, which is reflected in both her explanations for the cheetah and sparrow task, where science and human intervention can produce a change in "kind" and "body."

The last item in S's posttest is the cheetah task. In this item, S explains how cheetahs' running speed has gotten faster over thousands of years.

> S: I think they are maybe too long time, I think they might be because people. Long ago people are not humans they are just like some monkeys right. So I think this animal will maybe the time, like over time, then slow, slowly then faster faster faster like that.
> I: How do you think that happened?
> S: Because *time*, time can make them change everything.
> I: Okay, I want to make sure I understand your idea, so tell me more about that? How would that actually happen?
> S: I think because the time can change some thing because time is not waiting for people, not waiting for everything, then this cheet-, this animal, because time, they can over and over then they can grow, running faster, and going faster like that.

S brings up an analogy that she brought up earlier in her pretest for this item. She asserts that people were once monkeys. However, S's causal explanation in this item is dissimilar to that voiced in her pretest. In the pretest she believed that science made the cheetahs more powerful and able to run faster. Here she introduces a new idea—time—and how it can change everything, even the running speed of cheetahs. It is possible that S arrived at this idea to make sense of the explanation that was given to her in the previous item where "the sparrows got bigger and bigger." S reasons here that "time can make them change everything." She personifies time and says that "time is not waiting for people, not waiting for everything." One interpretation of this is that over time, without the help of people or anything, animals "can grow bigger" and "[go] faster."

Summary of S's Pre- and Posttest Responses

How do S's alternative conceptions change or persist after her participation in an instructional course that scaffolds the conceptual underpinnings of evolution? Reviewing S's set of explanations across her pre- and posttests, we see that her case offers valuable insight into the research questions that guide this study. S's pre- and posttest performance is one of many existence proofs from her cohort that young students at her age can make significant headway in progressing from expressing modest knowledge of evolution amid a multitude of alternative conceptions to developing a sophisticated understanding of the concepts underpinning natural selection.

In her pretest, S expresses many alternative conceptions that are common to her cohort (e.g., anthropomorphism, transformational, external agency). In the *Brassica rapa* item S's pretest answers hint at transformational thinking (the smooth plants growing hairs), though her explanation confuses the time parameters of the exercise and misses its generational focus. In the guppy, butterfly and sparrow tasks, she gives strongly anthropomorphic answers, constructing vivid stories to explain the phenomena she is addressing. The sparrow task also elicits transformational and external agency conceptions, as does the cheetah task that follows.

Similar to J and to her cohort, S displays a range of alternative conceptions in her explanations. Whereas J's interview revealed a strongly teleological bias, S's demonstrates a tendency to personify in her pretest answers. She applies human characteristics—not excluding speech—to most of the animals in the interview and in her responses to the sparrow and cheetah tasks suggests external human intervention as an explanation for evolutionary change. In the absence of a mechanistic understanding of change, S reveals a tendency to construct elaborate anthropomorphic stories to explain the distribution of traits in a population. For example, in the guppy task, the shift in distribution of traits is attributed to the predator fishes inviting each other out to feast on a meal of guppies. Her behavior is closely aligned with the finding of many cognitive psychology studies suggesting that children have a tendency to over-attribute human mental properties to non-human organisms (Heider & Simmel, 1944; Guthrie, 1993). From her pre- to posttest, a notable pattern emerges and we see that as she demonstrates her knowledge of the mechanisms of natural selection from pre- to posttest, her use of anthropomorphic explanations declines significantly.

S's explanations in her posttest reveal major progress in both the reduction of her alternative explanations and the development of her understanding of natural selection. With the exception of the butterfly task in her pretest, S early on did not attend to the variation of traits within a population and the survival advantage of particular traits under different environmental conditions. Here in her posttest, we see that S exhibits an understanding of natural selection in tasks that foreground variation (i.e., *Brassica rapa*, guppy, and butterfly). She can integrate the following ideas underpinning natural selection in her explanations: (a) survival advantage of trait, (b) reproductive value of trait, (c) inheritance, and (d) change in distribution of traits in a population.

To What Extent Can the Contexts Account for the Variability in S's Explanations across Contexts? It becomes evident from S's answers in her posttest that her explanations are highly context-dependent (see Table 18). S evokes normative conceptions in the three tasks (i.e., *Brassica rapa*, guppy, butterfly) that foreground variation and ask of her to generate a prediction and explanation of the population over one or several generations. However, S still harbors some alternative conceptions, which are invoked in tasks that do not foreground the idea of variation (i.e., sparrow and cheetah). She argues that people can play a role in changing the size of sparrows over time. She also brings up a new idea that cheetahs can change their running speed over time because "time can change everything." The variability of conceptions observed in both her interviews supports the idea that her knowledge is not coherent and consistent, but rather piecemeal. Initially in her pretest, S generated many spontaneous constructions that were in direct response to the situation of the question. However, in her posttest, we witness an alignment of reasoning across a span of tasks, as she applies several concepts underpinning natural selection to explain her prediction of the population in the *Brassica rapa*, guppy, and butterfly tasks. This alignment of knowledge elements into a coherent reasoning structure or "coordination class" has been identified by diSessa as a key step in science learning. S's gradual conceptual development is consistent with diSessa's perspective that the process of conceptual change is a process of reorganization rather than replacement. According to this view, existing pieces of knowledge are modified in terms of the contexts in which they are activated and used. In the case of S, we see the nature of her shifting knowledge resembles a collection of p-prims in her pretest, then coheres posttest into a more stable coordination class activated by specific knowledge elements according to context.

We can discern in S's progress from pre to posttest a change not only in comprehension but in method. Sinatra, Brem, and Evans (2008) suggest that the process of natural selection will not be popularly understood until students arrive at "an entirely new way of seeing." That new way may be glimpsed in S's posttest responses. To a remarkable degree, she moves away from the "magical" thinking (i.e., anthropomorphism, transformationism) of her pretest and grounds her answers in scientifically valid concepts. If she is unable to abandon entirely her concept of butterflies flying away from danger or sparrows saved from the cold by helpful people, her answers in these contexts are significantly less anthropomorphic, more grounded in proximate causality, than the storytelling she initially devised to address them. In this new orderliness of thought we see her potential for understanding the fundamental concepts of natural selection. Having engaged her interest and increased her familiarity, the instructional intervention has revealed what Metz (2011, p.7) terms, "the power of [her] epistemic capacity."

Chapter 6: The Case of B

"Well maybe because since they're cheetahs, they keep running. And like their parents die, and they grow up to be parents. And the parents tell them like a rolling advice 'keep running and pass this on to your children.'"

Overview

We next have B, a second grade student, who expresses a wide range of ideas, both normative and non-normative, in his pre and posttests (See Tables 19 and 20). In his pretest, we see that he has a tendency to construct a storyline as he anthropomorphizes the animals presented in the tasks. He also demonstrates a proclivity for inventing new explanations each time a question is raised, most of them highly spontaneous and apparently constructed on the fly in response to the situation of the question. In contrast to S, B starts out with an understanding of some prerequisite ideas of natural selection—such as population, variation, and survival advantage of traits. Unlike S, however, B does not demonstrate dramatic conceptual growth from his pre- to posttest. What we witness instead is a change of pattern in the elicitation of his alternative conceptions across his two interviews. Initially in his pretest, B displays multiple types of alternative conceptions across the range of tasks. These alternative conceptions include external agency, cyclical, anthropomorphism and parent-to-offspring transformationism. He makes progress in his posttest, as in the tasks that foreground variation he expresses normative concepts instead of those alternatives. Specifically, we observe a dramatic decline in his bias towards anthropomorphizing. However in those tasks that do not foreground variation, he reverts to expressing anthropomorphic, Lamarckian and external agency ideas. The contextual pattern that emerges in B's posttest is also representative of that observed on the cohort level.

Table 19.
Pretest Summary of B's Alternative and Normative Conceptions, Sorted by Episode

Pretest Episodes	Alternative Conceptions	Normative Conceptions
DESERT PLANT Explanation: how desert plants can survive with so little water	1~External Agent	
CRICKET Prediction and Explanation: one generation after arrival of caterpillar		1~Survival Advantage 2~Change in Distribution
CRICKET Prediction and Explanation: five generations after arrival of caterpillars	1~Flip in Distribution	1~Change in Distribution
GUPPY Prediction and Explanation: one generation after arrival of predator fish	1~Anthropomorpism	1~Survival Advantage 2~Change in Distribution
GUPPY Empirical Feedback: How is this different? How do you think that happened?	1~Anthropomorpism	1~Change in Distribution

Table 20.
Posttest Summary of B's Alternative and Normative Conceptions, Sorted by Episode

Posttest Episodes	Alternative Conceptions	Normative Conceptions
DESERT PLANT Explanation: how desert plants can survive with so little water		1~Needs of Organisms
CRICKET Prediction and Explanation: one generation after arrival of caterpillar		1~Survival Advantage 2~Change in Distribution
CRICKET Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Change in Distribution
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Survival Advantage 2~Change in Distribution
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Change in Distribution
BUTTERFLIES Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Change in Distribution
BUTTERFLIES Revoicing		1~Survival Advantage 2~Change in Distribution
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Transformationism	
SPARROWS Dynamic Assessment: Survival Advantage of Trait	1~Transformationism	
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage	1~Lamarckianism	
SPARROWS Revoicing	1~Lamarckianism	
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Anthropomorphism 2~Lamarckianiam	
DESERT PLANTS Explaining the fit between plants and their environment	1~External Agent	

B's Pretest: Unpacking the Normative and Alternative Conceptions

In the first task of the interview, the interviewer asks B, "How come plants in the desert can survive there where there's so little water?" B replies with a narrative.

> They can survive because the first people who discovered cactuses, they have saw how long they can survive in the sun with not so much water. So they created the cactus. They created all the spiny plants, cactuses, and then that is how they got cactus. And the cactuses cannot live anywhere else. But they could. They could, but anywhere that has flames. So they can't live near a fireplace.

Here B invokes the idea of an external agent playing a role in the creation of cacti or "spiny plants" that can survive with little water. His combining of the terms "discover" and "create" and the disjointed chronology of his narrative reveal an ad hoc approach to the construction of his explanations.

In the next task, the interviewer tells B about the case of chirping and mute crickets on the island of Kauai. When she informs him about the arrival of the flies that lay their eggs inside the crickets' bodies and asks B how he thinks the flies would find the crickets, he answers, "The chirping, so these [points to mute crickets on island] are mostly most valuable cause they won't get eggs in their bodies because they can't chirp."

The interviewer then asks B to show his prediction for the next generation of crickets on the island and B lays down 13 mute crickets and five chirping crickets. Note that B refers to the types of crickets by the color of the borders on their respective icons, where the chirping crickets have red-bordered icons and the mute crickets have blue-bordered icons.

> B: I added a lot of 'em, I think that the red [chirping] types, the red crickets could not have survived that long. So one year generation after all those flies reached all those chirping crickets, may not survived. I left a few, these two red crickets out because y'know flies can still find some, so this is why I think this island will look like one generation later after the flies have swarmed them.
> I: So remember these [points to generation 2] won't be the same crickets because crickets don't live that long. It'll be the next generation. So crickets mate and have babies that grow up to become adult crickets.
> B: Right.
> I: So this is what you think it'll look like one year later. And you said that you don't think the red ones will survive. Why did you say that?
> B: Because their chirping will get the flies to find them, and then the flies will lay their eggs in them. And the flies are so sneaky they can just crawl on them and lay their eggs. But the blue crickets, as you can see, have lots and lots more than the red crickets, because they don't chirp, they have the most advantage of the red crickets, because they have chirping and the others don't.
> I: Which ones have chirping?
> B: The red types. So that's what usually will happen the generation later.
> I: And how would that happen?
> B: Because the red crickets don't have ridges that can make them chirp. The blue crickets don't really have chirping, they can't rub their wings and chirp. That way they'll have the most of the red crickets, so that way they will, the red will not survive yet the blue will.

B predicts that there will be more mute crickets in the following generation, explaining that the mute crickets will "have the most advantage" because the flies won't be able to find them. He shows a clear understanding of the survival advantage of being a mute cricket and its effect on the distribution of traits in the population. His characterization of the flies as "sneaky," however, hints at an anthropomorphic characterization we will see expressed more assertively in tasks to come.

The interviewer asks B what he thinks the island will look like another three generations after his prediction for the second generation.

> B: Probably a little different I think, as in there will be more red flies because the babies will be born.
> I: Whose babies will be born?
> B: The red cricket flies and the flies will maybe will find some of these guys [non-chirping] so I'm taking them out and replacing them with reds, cause the reds will have babies and they will grow up to be adults, and so the reds now are catching up to five generations later [lays down 11 chirping, eight mute cricket icons].
> I: How do you think that will happen, what will happen to these guys [points to mute cricket]?
> B: Those guys might still last for a lil' bit longer than usual but they still might die because of the flies but since it's five years later perhaps more flies will be crawling in.

B here abandons his earlier ideas that expressed the survival advantage of being mute and now proposes that the flies will eventually find the mute crickets to lay their eggs in. The die-out of the mute crickets will give way to the proliferation of chirping crickets "catching up" five generations later. His idea that the distribution of traits will switch after several generations is not an uncommon response among his peers with respect to questions that ask for predictions of a population over multiple generations. Some students, like B, believe that there is a bidirectional cycle to the distribution of traits over time, as opposed to the normative idea that a trait conferring survival advantage under particular environmental conditions will continue to become more common in a population over many generations.

Turning to the guppy task, the interviewer asks B to make a prediction for what the next generation of guppies in the pool will look like after the arrival of the predator fish. B lays down 16 gray guppies and five yellow guppies.

> B: Before the predator fish got there, there were thousands of colorfuls and not many grays. But now that the predator fish are there, the gray fish are not really what they're after. I think they're really after the colorful fish. The colorful fish, I think, have the best taste.
> I: How come they're not really after the gray fish?
> B: Because the colorful fish may have been after [inaudible] year before. The gray-guppies-eater may just actually want to attack the colorful fish but the gray fish usually stay below or above water and maybe they will stay alive.
> I: How will the gray fish stay alive?
> B: If they are above or below.
> I: Above or below what?
> B: Above or below the water. If they're above, then the guppy fish can't get that high, the guppy-attackers cannot get that high, they cannot reach. And if they're below, they will actually just be after the colorful fish, because they don't want to be eaten by a shark

> or something like that. And the lower the lower you go, the more danger it gets, the more danger there is. Cause like if you were at the bottom of the ocean, that's danger, and the other fish will attack. If you were above the water, they would think, "Oh that's not the fish we're looking for, c'mon let's go." And if you were a fish you could camouflage if you had a white chest down like that [gestures a hand motion running down his chest] and on like that, you would have a white chest and fin and you can swim and they think you're a piece of the sky.
> I: So how will it happen that it'll go from this to this? How will that happen?
> B: Because the gray guppies may have been not after for. Maybe it was the colorful guppies, that's why I put all the gray guppies over there and less colorful guppies.

B displays a shift in the distribution of colored and gray guppies in his prediction for the second generation. His answer initially suggests an understanding of the survival value of being a gray guppy as he attributes the disadvantage of being a colorful guppy to their flavor. He develops an elaborate explanation describing the gray guppies finding refuge "above the water" where the predator fish can't reach them or far below where the danger is greater and the predators are themselves at risk of being eaten by sharks. He anthropomorphizes the predators, giving them dialogue: "Oh, that's not the fish we're looking for, c'mon let's go" as he suggests how the color of the gray guppies can confer a survival advantage. As evidenced in many of B's responses, his propensity to anthropomorphize the targeted organisms of the evolutionary phenomena often parallels and sometimes overrides the expression of his normative ideas.

The interviewer shows B a template displaying "what the scientist actually saw," asking B to explain how the two generations are different.

> B: Because the gray guppies have had made an escape, and the colorful guppies didn't know what to do, so they got eaten.
> I: How did the gray guppies make an escape? What do you mean?
> B: They [gray guppies] made a small plan and they got out of the way of the gray guppies, and plus to get out of the whole guppy thing, they [the gray guppies] told [the predator fish] where the colorful guppies were, and they got eaten, the colorful guppies got eaten.
> I: Who told where the colorful guppies were?
> B: The gray guppies. So they attacked in that area, the predator attacked the same area where the gray guppies told them and they stayed out of the gray guppies way because they're the ones that helped them find the colorful guppies.

Although his prediction and the empirical feedback are very similar, B abandons his earlier ideas about the survival advantage of being less "tasty" and able to camouflage and creates instead a story to explain "what the scientist saw." His story involves the anthropomorphism of the gray guppies, where "they made a small plan" and "told [the predator fish] where the colorful guppies were."

The interviewer then asks B to make a prediction for what the next three generations of guppies will look like. B places all of the gray guppy icons down on his template.

> B: Well, because all of the colorful guppies are eaten. So those [gray] guppies are actually the ones these eaters are trying to capture, these guys [the gray guppies] cause

they didn't actually tell the truth, there wasn't much food here [points to generation 2] and that's how they were eaten, but they still almost all of them survived.
I: So what happened to the colorful fish?
B: The colorful fish have been eaten, all of them have been eaten. And I'm thinking, hey, maybe the gray guppies still survived so, and I think they did. So they're going up they're trying to escape the killer fish, the predator fish.
I: How did it happen that it went looking from this [points to generation 2] to looking like this [points to generation 5]?
B: So I'm thinking the colorful guppies have been eaten so the gray guppies must have still survived somehow. But the killer fish thought there were still some more colorful fish and they [the gray fish] lied that there were more because they ate them all.
I: Who lied?
B: The gray. And a few generations after this came this [points to generation 5] where they are trying to capture the gray fish and eat them for their breakfast and well you know what I mean.

B displays a shift in distribution from mostly gray guppies (i.e., 16 gray, five colorful) in his prediction for generation two to all gray guppies in generation five. His explanation for that change entails an elaboration of his earlier anthropomorphic story, where the colorful guppies got eaten because the gray guppies told the predator fish where the colorful guppies were. He attributes intentional qualities to the gray guppies. According to B, they were "trying to escape the killer fish" and "lied" to the predator fish about how much food (i.e., colorful guppies) was there for them to eat. B attaches psychological attributes to the predator fish when he explains that the predators "thought there were still some more colorful fish" and after several generations "they are trying to capture the gray fish and eat them for their breakfast." Unlike his first prediction for one generation later, B does not mention here the survival advantage of any trait that the gray guppies may have (e.g., worse taste, camouflage). Rather, he attributes their prevalence in generation five to their deceitfulness.

Of note here is the mix of normative and non-normative ideas B employs to arrive at his prediction. While he continues to insist on the prevalence of the gray guppies in the pool, his explanation of how that dominance occurs is grounded in an anthropomorphic interpretation. Beginning with a vague idea of the gray variant's survival advantage—whether color or flavor—he goes on to construct a series of narratives to account for the gray guppies' ultimate endurance in the population. The question raised by B's answer is whether his prediction reflects some basic level of understanding of the survival advantage of being gray "backed up" by a fanciful rationale or whether the prediction is an accident of choice and the anthropomorphic rationale drives his thinking.

The interviewer next shows B a template of a group of Banded Peacock butterflies. There are eight butterflies with green-striped wings and two with plain black wings. The interviewer tells B that a new kind of bird arrived at the place where the butterflies live and they seem to attack the ones with striped wings. She displays four templates and asks B if one of the four templates shows what his prediction for the next 50 generations of butterflies will look like. B chooses the second template, displaying five striped-wing and five plain-winged butterflies.

B: This one, yeah [points to half and half template]. Because since the birds have eaten all those [striped] butterflies, and the butterflies don't last long. I think it'll be half and half because five young children of the [striped] butterflies and five plain ones.
I: Which butterflies? Five young children of the [probe for which ones got eaten]?
B: Striped butterflies. And five young plain butterflies.
I: Before you said that the birds would eat all of the butterflies, which ones were you talking about?
B: All of the striped ones because they have like colorful wings, so they have the most attention. So they could have eaten these three [points to striped-wing butterflies in original template] and replaced them the black butterflies, taken those three, and now it looks like this [points to half and half template].
I: The black butterflies would have taken those three? Is that what you said?
B: They could have eaten those three [points to three striped butterflies in original template] and they could've replaced them [points to black butterflies in half and half].
I: How did they get replaced?
B: They got replaced by the black butterflies, who are still surviving better than the green butterflies.
I: Why are they surviving better?
B: Because they could hide in the dark and so they could not get eaten much, so they can hide in the dark, stuff like that.

In this episode B does not express any alternative conceptions. His prediction shows an eventual shift in distribution or "replacement" of striped butterflies with black ones over 50 generations. He articulates the survival advantage of being plain-winged, in that they can camouflage and are less likely to get eaten by the birds. It is interesting that despite similarities in the guppy and butterfly tasks (trait variations based on color, the introduction of an environmental press), B does not devise a narrative to explain his prediction and does not anthropomorphize the butterflies as he did the guppies.

The interviewer gives B a hint that the plain-winged butterflies are more likely to survive than the striped-wing butterflies. B changes his mind and chooses the fourth template, which displays all black-winged butterflies, and explains his choice to the interviewer, "I think that it would be all plain because all those green butterflies could've been eaten, they could've been taken down, and then the birds flew away to find others just like them."

When the interviewer scaffolds the idea of inheritance and the survival and reproductive advantage of being black-winged, B maintains his previous idea.

B: Well I'm thinking that it'd still be all plain and that the birds are still searching for the green butterflies, but they cannot find them.
I: How come they can't find them?
B: Because they might have eaten them all in the area that they are living in. They're searching all in the area but they can't find them.

The interviewer then tells B "what another student said," which is the natural selection explanation. She asks B to explain what that student's explanation meant.

> B: I'm thinking that that kid meant that the number of the striped butterflies could have reduced, have been taken away, and eaten. And they get lower and lower then soon it will be two, then none. So that's what the kid meant, I think.
> I: And do you agree with him?
> B: Hmm, not as well as I agree with myself, but maybe.
> I: What don't you agree with?
> B: I'm thinking like that he didn't really get the idea. I think the striped butterflies might have been eaten and all switched numbers [switches templates 2 and 3 around] like these numbers. I think it's supposed to be like that [points to template 1], that [template 2], they have babies, that [template 3], then none [points to template 4]. So I didn't think that is reduced in number like duh, duh, none [gestures to templates 1, 2, 3, 4]. I thought it was like duh, duh, duh, none [gestures to templates 1, 3, 2, 4]. So it was very different.
> I: Why do you think it would change like that?
> B: Because if they [points to striped-wing butterflies in template 1] have been like that [still pointing at template 1], they could have died. Two of them [points to two striped-wing butterflies in original generation] could have survived [points to the two striped-wing butterflies in template 2]. And then those two could have babies [points to the striped-wing butterflies] and could have three children. These five children. And then the children would have been eaten, and there would be none left [points to template 4].

B explains how the other student believes that the number of striped-wing butterflies will "get lower and lower" until there are "none." He doesn't agree with the student's idea of gradual reduction of striped-wing butterflies. B switches template 2 and 3 around to display what he thinks will happen over 50 generations, reasoning that there will be more striped-wing butterflies after an initial decline because "they [will] have babies." This back and forth distribution pattern is similar to B's prediction and explanation for what would happen to the crickets on the island of Kauai in generation five (Episode 3). In that context, he argued that the "reds [chirping crickets] will have babies and they will grow up to be adults, and so the reds now are catching up to [the blue, mute crickets] five generations later." In this episode, B's cyclical conception does lead to the eventual extinction of the striped-wing butterflies, their resurgence serving merely to delay that end. Typically, he asserts his theory with confidence. Does he agree with the other student's explanation? "Not as well as I agree with myself."

Proceeding to the next task, the interviewer asks B how come House Sparrows have gotten so much bigger over the past 100 years.

> B: I don't know. I think there's a lot of cold, and since their parents were all puffed up, I think their skin's a little lower. But they think they actually are a little puffed up, yet they are, but I still think that they're not so puffed up at all. They're small and they're just covering up with a sheet of feathers they find along the way. I think these are young baby children [points to original 100 years ago template], and this is the youngest [points to the small sparrow in original template] because it's the smallest and these two are babies [points to two small sparrows in original template] because they were the two first born and they have the skinniest part, the skinniest feathers.

B initially voices a tentative explanation that the sparrows have gotten bigger because they are covering themselves with feathers that they have found. He then expresses another idea that the smaller sparrows are the youngest. He takes the position that the size of the sparrow correlates with their age.

After offering B a hint about the survival advantage of being bigger, the interviewer asks again the original question: How come the sparrows have gotten so much bigger over the years?

> B: Well that was because, they have collected feathers I think. And they collected feathers and some of them have joined the six [points to the sparrows in colder climates template] and the size of them may have grown up so their skin's a little puffier.

B returns to his earlier ideas that sparrows have collected feathers. He adds that the "size of them may have grown up." It is unclear whether he is repeating his idea that the sparrows grew bigger with age or is making a new assertion that they grew in size through another process.

When the interviewer reads to B "another student's explanation," which is the natural selection explanation, B explains to the interviewer what this other student's explanation meant.

> B: I think that kid meant that these small ones may have gotten a little bigger and a little bigger and they got to this size. But soon after that, they have babies. And now they live in the warm places because the babies are so small, and they don't have that much feathers around them.
> I: And do you think that kid was right or wrong?
> B: I think that kid was right.
> I: You think he was right? How come?
> B: Because they look small, medium 100 years ago, today in cold places, they look bigger. And that kid was right. They got a little bigger, and then they got a little bigger. And that kid was correct.

B's explanation is consistent with his earlier idea that the sparrows will grow as they grow older.

The next question evokes from B an empirical response that is literally grounded in his own experience. The interviewer asks how come cheetahs have gotten to be so much faster than their ancestors who lived thousands of years ago.

> B: I'm thinking that now that these were a thousand years ago and they can only run 25 mph they didn't have much paw going into the earth. They're not connecting to the earth. They're not reaching into the energy and lifting up. So they couldn't touch the earth as well as these guys can. These are the cheetahs today [holds up one of the pictures] and these are the cheetahs that run 25 mph [points to another picture] a few or a more than a few years ago, so I'm thinking hey they're not reaching into the earth like we Japanese people do. I take Aikido.
> I: Ah, I see.
> B: So they're not reaching into the earth and grabbing the earth and taking its energy to itself and running as fast as it can.
> I: So how do you think it changed from a thousand years ago?
> B: Well, because these African cheetahs they came to the cheetahs that are northern and they taught them how to reach into the earth and take its energy now almost every cheetah in the world, by the north and in Africa can run as fast or the same. This is a thousand years ago cheetah and this is today's cheetah [shows with two fingers of each

hand the legs of the cheetahs running on the desk, the left hand represents the cheetahs from a thousand years ago, the right hand represents the cheetahs from today, which runs faster].
I: Oh I see.
B: And this is when today when the northern cheetahs that lived here now and the African cheetahs run the same [shows with fingers of both hands the legs of cheetahs running at the same speed].

B begins his lively explanation with the idea, "I'm thinking…they didn't have much paw going into the earth." He reasons that the cheetahs that lived thousands of years ago were "not reaching into the earth and grabbing the earth and taking its energy to itself and running as fast as it can," an idea he appears to have drawn from the notion of "grounding" in the practice of Aikido. B anthropomorphizes the cheetahs as he goes on to explain how the African cheetahs taught the cheetahs in the north their technique of "reaching into the earth." The result of this schooling, according to B, is that cheetahs today can run much faster than their ancestors.

Next the interviewer shows B pictures of different plants that live in the desert. She describes how each plant has a structural feature that helps it survive in a dry climate and asks B to explain how come most plants fit so well where they live.

B: Well that these plants look very spiny and stuff. So if they are spiny the animals cannot get inside, yet the water cannot get out. So I'm thinking, hey, it rains in the desert. Why can't they just suck the water in, and why not just take it out and give it to the rest of the plants. So there are a lot of things that could have happened. A lot of things could have changed in a thousand years when these plants first showed up.

B explains the fit between the desert plants and their environment in a "why not" manner. He reasons, "Why can't they just suck the water in, and why not just take it out and give it to the rest of the plants?" He believes that there might be a mechanism in the structure of plants that allows them to distribute their moisture to "the rest of the plants." This "why not" formulation may provide a clue to the variability that characterizes many of B's responses.

Summary of B's Pretest

What are the alternative conceptions that B has about evolution? In his pretest, B expresses an array of alternative conceptions. He cites external agent intervention in the desert plants task and applies an idea of cyclical trait distribution in the cricket and butterfly items. Like other children in his cohort, B often expresses anthropomorphic ideas when contemplating evolutionary change. He structures his answers as narratives in which the participants—whether crickets, guppies, butterflies or cheetahs—speak to each other, develop plans based on human motivations and in one instance (the guppy task) betray each other through lies and connivance.

How variable or consistent are B's alternative conceptions across the range of tasks in his interview? To what extent can the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in his explanations across contexts? Variability is a striking feature of B's pretest responses. The spontaneous quality of his answers, the sense that each new context promotes a different idea, seems to generate its own independent momentum. In the guppy task, for example, B's anthropomorphism appears to be the dominant theme in his explanation. He invokes the survival value of camouflage and its effect on the distribution of traits in his prediction for the second generation, then abandons that normative idea and anthropomorphizes the guppies and predator fish to explain "what the scientist saw." The anthropomorphism continues in his explanation of the fifth generation. In the cricket and butterfly tasks his grasp of certain normative ideas such as within-kind trait variation and survival advantage of traits seems relatively strong. In both contexts, however, B compromises his initial normative ideas with a cyclical conception to explain the trend toward change of trait distribution in the population.

Similar to J, B's interview demonstrates how a student can invoke both a scientifically acceptable and alternative conception within the context of the same task. However, J and B's individual set of explanations reveal a different relationship between their normative and alternative conceptions. Throughout J's pretest interview, we witness a progression from alternative to normative in many of his responses (i.e., to tasks foregrounding variation). However, from the beginning to the end of B's interview, we do not have a sense that he is making conceptual progress. His answers tend to fluctuate from normative to non-normative (and back) from task to task. In the following section, we see how this pattern of reasoning shifts—though some of B's alternative conceptions persist, while new ones emerge.

B's Posttest: Revising the Narrative

B's posttest begins with a reprise of the first question of his pretest: How come plants in the desert can survive for so long without water?

> B: They can survive there in the desert, because, well, as I think, I always think first there's this [points to rainforest] and this [points to desert]. This [desert] doesn't have enough water, this [rainforest] does. If we combine them, there'd be water, but not that much sun. So I always think, opposite. So since these plants [desert] are always cactus plants and stuff like that, cactuses ONLY need a little bit of water almost every day. And the rainforest needs at least half a cup of water every day, or a whole lake, half a lake.

B's explanation differs from that in his pretest, where he suggested that people created the cactus plant. Here his explanation is based on the needs of plants. He mentions that he "always think[s] opposite" a phrase that may indicate he's thinking backwards from the desert environment to the needs of the plants that live there.

Returning to the cricket task, the interviewer asks J to predict what the next generation of crickets on the island of Kauai will look like after the flies have arrived. B lays down 12 mute crickets and six chirping crickets.

> B: I think there'd still be six of the, there'd still be at least a little of the chirping crickets and a lot of the non-chirping crickets cause you can't hear them rub, when they try to rub [gestures with his both arms to simulate cricket wings], you only hear [rubs fingers together, making no noise]. So that's why then there's not much of these [holds chirping cricket up] because if you hear the chirp [holds picture of fly laying eggs in cricket's body] the flies come [points to fly] to this kind of cricket [holds up chirping cricket], eats it up, [removes the chirping cricket from the table], and this one [picks up mute cricket] takes its place.
> I: How would that happen?
> B: Because the fly would come for these guys [picks up chirping cricket] because they have the power to chirp, not like these guys [picks up mute cricket]. The fly would come

to the chirping cricket, eat it up, the other one takes its place, and well, that's how it happens.
I: The other one takes its place? Tell me how that happens.
B: There's two crickets. There's a fly. Fly comes to the male cricket that can chirp. Eats it up. The babies eat it up. And then this one [mute] is still left, and it takes, and it y'know, does what it has to do to be like one of these [the chirping cricket], besides the chirp. So it's like taking a place for another person.

Asked to carry his prediction to the fifth generation, B proposes 12 mute and three chirping crickets.

B: This is what she saw 15 generations. This is what she saw in the fifth generation [added two more chirping crickets:12 mute, five chirping].
I: How do you think that'll happen? Tell me what you just did. Can you give me a playback?
B: So, it's like, say like there's 99 crickets on the island. There is, since there used to be all of these reds [referring to the color of the border of chirping cricket icon]. Fly came [picks up fly-laying-eggs-in-cricket-body picture]. Ate the reds. Then the blues couldn't chirp, and, well, there'd be at least one blue [referring to color of the border for mute cricket icon] taken away. Instead I added more because, well, the flies only go to the chirping crickets.

B's prediction for the next generation of crickets shows a clear shift in the distribution of traits. His prediction and normative explanation in this episode is similar to that of his pretest. He explains the survival advantage of being mute and its effect on the population of crickets.

His prediction for the next five generations of crickets, however, differs from that of his pretest. In his pretest, B predicted a cyclical fluctuation of traits with more chirping crickets because "the flies will maybe will find some of these guys [mute crickets]" and "the reds will have babies and they will grow up to be adults, and so the reds now are catching up to five generations later." In the posttest, B does not posit a cyclical conception. He first displays what the scientists saw 15 generations after generation two (12 mute, three chirping crickets) then he adds two more chirping crickets to display what he believes the scientist will see five generations after generation two. His prediction demonstrates a general decline in the number of chirping crickets over the generations. He then explicates the survival advantage of being mute and how it results in a shift in distribution of the trait in the population of crickets. His prediction and explanation in this task is the first instance in which he reveals his understanding of the accumulated changes over many generations.

B's development of normative concepts is also demonstrated in the guppy item. In his prediction for the next generation of guppies, B lays down 12 gray guppies and five colorful guppies and explains to the interviewer how his prediction for generation two of the guppies differs from generation one.

B: These guppies are different because there are not so much colorful ones. And because the gray guppies, they can blend in with the rocks down below. And these guppies can't blend in with anything, unless it's a coral reef. So, yeah, they get eaten by either these guys or the coral reef. If they try to blend in with the coral reef, they'd be eaten by that one, or if they were near the predator fish, they'd be eaten by that one.

When the interviewer shows B "what the scientist actually saw," B interprets the empirical feedback and explains.

> B: Because the colored guppies have been reduced and a different form, they no longer like have a whole school. The gray guppies have the school. The colored ones don't really.
> I: How do you think that happened?
> B: Cause the predator fish found the colored guppies. The colored guppies, these [picks up colorful guppy], cause they're so colorful.

The interviewer then asks B to make a prediction for what the next three generations of guppies will look like. He lays down seven gray guppies and four colorful guppies, explaining how the guppies in the fifth generation are different from the ones in the second generation.

> B: They're different. Because, well for one, if this was real life, they'd be in a pattern [gestures at the generation 5 prediction]. And two, is that these guys [points to a predator fish] have been going for these guys [points to colorful guppies] mostly, because they're the ones most colorful. But these guys [points to gray guppies] stopped blending in, cause these guys [points to colorful guppy] may have the most meat inside of them, the most muscles. These guys [holds up predator fish] mostly don't want these guys [picks up gray guppy] because they don't have enough meat. But they do want these guys [picks up colorful guppy] because they have meat inside them.
> I: So what do you have here? Can you tell me what did you lay out?
> B: I laid out only a few colorful ones and only a few gray ones.
> I: How will that happen? That it looks like this [gestures to fifth generation prediction] and three generations before, it looks like that?
> B: Well, um, because, these guys [predator fish] want these guys most [colorful guppy] because they have the most meat in them. These guys don't have as much muscles inside of them so they don't have enough meat on them. These guys can only last for at least 12 hours. 12 hours only. These guys, at least 39, 36, 31. Well actually these guys [gray guppies] 31 minutes. These guys at least 12 hours. Cause they have enough meat in them and enough muscles and they're color-coded so they're easier to see.

In this exchange B explains the survival risk of being a colorful guppy living in its environment (the pool template is gray with rocks). He reasons that the colorful fish "can't blend in with anything, unless it's a coral reef" thus showing an understanding of the relative nature of survival advantages of traits and how they are dependent on the conditions of the environment.

Both his explanations for "what the scientist saw" and his prediction for the next three generations in the posttest differ from his pretest answers. There he explained the prevalence of gray guppies by anthropomorphizing both the guppies and predator fishes in the pool (i.e., the gray guppies told the predator fish where the yellow guppies were). Here in the posttest he remains consistent with his explanation about the survival advantage of being gray across all three items of the guppy task—though in mid-explanation he abandons the color trait advantage and invents one of his own: relative meatiness, which he translates into corresponding life expectancies with comical precision: "These guys can only last for at least 12 hours. 12 hours only. These guys, at least 39, 36, 31. Well actually these guys [gray] 31 minutes."

Returning to the butterfly task, the interviewer asks B to predict what he thinks the next 50 generations of Banded Peacock butterflies will look like after the arrival of the attacking birds. B picks up the second template, which displays five striped and five black-winged butterflies.

> I: And why do you think it'll look like that?
> B: Because they can't eat ALL of them. Because there still has to be a little bit left. Because if I chose this one [picks up template one]. Wait if I chose this one [picks up template three] or this one [picks up template four], I'd just end it already. So I decided to make it longer on this one by choosing four [referring to his perception of the number of both black and striped butterflies in chosen template, there actually are five each]. And also that the black ones aren't really attacked so much, so this has more blacks than greens [the template he is holding actually has equal amounts of striped and black-winged butterflies].

In describing his rationale for choosing the second template, B reasons that he would "end it already" if he chose template three or four (displaying mostly black-winged butterflies and all black-winged butterflies, respectively). He opts for template two "to make it longer." Here we may assume that by "it," he is referring to the existence of the striped-wing butterflies. His decision not to "end" their existence hints at his understanding of the trajectory of the gradual shift in distribution of traits over many generations. It also suggests a subtle external agency[1] and B's reluctance, as the external agent, to push the species to extinction.

The interviewer then scaffolds to B the idea of inheritance and the survival and reproductive advantage of being a black-wing butterfly. B reconsiders his prediction.

> B: Ummm [pauses to think] I think it'll look like this 50 generations later [picks template three with eight black, two striped butterflies].
> I: So how do you think it'll happen that it'll look like that?
> B: I think that'll look like that because well, look how much on this one [points to template two], four, there's four of 'em. And there's two here [points to the two striped butterflies in template three], so if they all combine, if these two were the grandpa [points to two striped ones in template two], these two were the parents [points to two other striped ones in template two] and this extra one was like an uncle or aunt. They'd only have these two children [points to the two striped butterflies in template three]. These guys [the "grandparents"] took care of these guys [the "parents"] and this guy [one of the "parents"] or this guy [the other "parent"] or this guy [the "uncle"] would be brother and sister and then the grandparents and the mother and father would have the two babies [picks up template three]. The grandparents could still be alive, because, well, yeah.

B changes his mind after the dynamic assessment hints and chooses template three as his prediction. When asked how that would happen, B begins to describe the relationships between

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[1] Note that this episode was not coded for an external agency conception because the student did not refer to an actual external agent in his explanation for the change in distribution of traits.

the butterflies on template two and three. He sees the butterflies on template two as a combination of two generations of butterflies (i.e., grandparent, parents, aunt, uncle). He points out that the two butterflies in template three are children, hence the next generation. He relates the idea of generations to familial relationships, where there are clear relationship identities such as grandpa, parent, uncle, and they take care of one another. The life span of butterflies, according to B, is similar to humans in that "grandparents could still be alive" in the same lifetime as the parents.

The interviewer reads to B what "another student said," and B interprets this student's explanation.

> B: I think this kid meant that maybe there wouldn't be any more striped ones left after the ending, there'd only be plain wings. And then, where it gets smaller and smaller [sweeps hand across all four templates]. I think that kid was correct, I mean it's getting smaller and smaller each generation. Well maybe this kid was more exact, like saying, that there'd be none left, and that it would get smaller and smaller each generation.

B interprets this student's explanation to mean that the shift in population, with the number of striped butterflies getting "smaller and smaller," would lead to the striped butterflies' extinction. He agrees with the other student's idea and adds that he "is more exact" in "saying that there'd be none left."

The track of B's responses in the butterfly context exemplifies an ad hoc approach to the construction of his explanations. His normative and alternative conceptions ebb and flow across the range of items in both of his interviews. In B's pretest his initial prediction and explanation for the butterflies demonstrates an understanding of the survival value of being a black-winged butterfly, an understanding he appears to compromise when a dynamic assessment prompt ("what another student said"), leads him to express the idea of cyclical trait distribution. Returning to this context in his posttest, his answer to the first item considers the change in distribution of traits over time, but does not mention the idea of survival advantage of wing color trait. His answer to the second item switches to a contemplation of the butterflies' family structure. In his response to the last item of the task, B circles back to the idea that the population of striped-wing butterflies will decrease over many generations.

The interviewer next asks B to explain how sparrows have increased in size over 100 years.

> B: Well maybe since this was 100 years ago. Maybe this person who found it a hundred years ago, found some of the birds in hot places, and then he found some in cold places. These guys have been in the cold places the longest. And I think that the hot sparrows stayed in the hot places because they like the hot and in the hot they're smaller. And today in cold places, they get bigger. Because well if the cold makes them bigger and bigger, they get bigger and bigger in size and shape and in amount, in numbers.

Here B offers another spontaneous rationale encompassing multiple ideas. He believes that the "cold makes [the sparrows] bigger" and that the sparrows stay in the hot places because they like the heat. B suggests the environment determines the size of the birds, the cold itself is the driving mechanism that makes them bigger.

The interviewer offers a clue about the survival advantage of being bigger in colder climates and then asks B again how come the sparrows have gotten so much bigger. B replies, "Well because they've been in the cold longer." The interview continues with the dynamic assessment and the interviewer scaffolds the concept of inheritance and the survival and reproductive value of being bigger in cold climates and then repeats the original question of how come sparrows in cold climates today are so much bigger than the ones from a hundred years ago.

> B: Well maybe because of the parents that they had were medium-sized and they grew up to be a bigger size. And well, they're inherited by size, correct? So these guys [points to cold places sparrows] inherited a lot more than their parents. These guys [points to warm places sparrows] were a lot like these guys [points to 100 years ago sparrows] but smaller, so these guys didn't really inherit anything from their parents.

B's new idea suggests that the parent sparrows were "medium-sized and they grew to be a bigger size," and their children that lived in the cold places inherited "a lot more" from their parents than the sparrows that lived in warm places. This is the first instance in which B expresses a near-Lamarckian idea, where the children inherit the acquired characteristics of their parents. His version of soft inheritance is need-based, in that the sparrows will inherit as much big-ness from their parents as they need in order to survive in their current climate.

When the interviewer reads to B "what another student said," which is the natural selection explanation, B agrees with this explanation. However he interprets it differently from how it was intended.

> B: I think this kid meant that in the cold that they get a little bigger and a little bigger. Because, well, they're sparrows, living things, they're mammals like us. And we grow up to size and then we pass on our size to them and then to our children and they grow up, grow up and grow up and when they grow up, they're getting higher and more in size.
> I: You think this kid was right or wrong?
> B: Definitely I think this kid was right.
> I: Why?
> B: Well, because this kid said they grow. They get higher and these guys [points to sparrows in warm climates] get lower and lower in amount, and in size and maybe, and just maybe in age.

In his explanation, B analogizes the sparrows to humans, reasoning that we "grow up to size and then pass on our size" to our children and implying that our fellow mammals do the same. His reasoning is similar to the near-Lamarckian concept of his previous answer. According to B, there is a cycle in which a parent's acquired size gets passed down to the offspring.

In the next task, the interviewer asks B how come cheetahs today can run so much faster than their ancestors. B provides the interviewer his explanation.

> B: Well maybe because since they're cheetahs, they keep running. And like their parents die, and they grow up to be parents. And the parents tell them like a rolling advice "keep running and pass this on to your children," they keep running keep running and thousands of years later they might have gone up to be as fast as a car or more fast.

> I: Any other ideas?
> B: Well, maybe they could have also used their tails to balance. They could have used their tails and each time their tails grew the longer they go, the longer they go in running, and faster they go in running.

B's pretest answer to this question drew vividly on his own experience with Aikido and the idea of cheetahs teaching each other the technique of taking energy from the earth. No hint of that reasoning remains in his posttest explanation. He replaces it with two new alternative conceptions. He first explains how cheetahs pass on the advice "to keep on running" to their children and urge those children to do the same with *their* children, with the end result that after thousands of years a cheetah can run as fast as a car. Though B's explanation is unclear as to whether each generation passes on its speed to the next or just its advice, in either case he anthropomorphizes the cheetahs to explain how they have gotten faster. B's other explanation suggests that the cheetahs use their tails to balance and their tails grow longer each time they are used. And when their tails grow, the "longer" and "faster they go in running." This explanation relates to the Lamarckian idea of "use or disuse," where change in organisms' can occur due to their use or disuse of an organ. Here B believes that the more the cheetahs use their tails to balance themselves, the longer their tails will grow.

In the final question of the posttest the interviewer shows B pictures of different plants that live in the desert and describes how each plant has a structural feature that helps it survive in the desert. When she asks B to explain how most plants fit so well where they live today, B uses the desert plants that were discussed as an example of fit in his explanation.

> B: Well I think since they're well-adapted to where they live. These two [points to the two cactus pictures], I know this one looks feathery but it really looks like this. Even those there two plants have mostly, are mostly in common to each other, they both mostly have been where they have been at least a couple hundred years ago or maybe even thousands. And well, I don't know the story to it, but maybe some scientist made this new kind of seed and planted it in the ground and made these plants, just sayin' maybe.

B offers a tentative external agency explanation for the fit between plants and their environments. He proposes that a scientist "made this new kind of seed" and "made these plants." He adds as a caveat to his conjecture that he is "just sayin, maybe" and is not certain if that was what really happened. As in his "why not" locution in the pretest, this "just sayin' maybe" suggests that his explanations could be framed as a series of hypothetical trials, which could account for the highly variable nature of his alternative conceptions.

Summary of B's Posttest

How do B's alternative conceptions change or persist after his participation in an instructional course that scaffolds the conceptual underpinnings of evolution? And to what extent can the contexts account for the variability in B's explanations across contexts? Compared to the other case study students, B shows the most modest improvement in both his reduction of alternative conceptions and gains in conceptual understanding of normative ideas. His set of normative concepts (i.e., survival advantage of trait, change in distribution of traits in a population) remains relatively consistent from pre- to posttest. Similar to the other case study students and his cohort, his explanations in the first four tasks of his posttest (i.e., rainforest/desert plants, cricket, guppy butterfly) demonstrate a notable movement from non-normative to normative reasoning. In the guppy item, for example, B's pretest answers rely extensively on anthropomorphic formulations which disappear entirely in his posttest responses. Also like his cohort, B continues to express alternative conceptions in the last three tasks (i.e., sparrow, cheetah, desert plants) that do not foreground within-kind variation.

Both B's style of response and his array of varied explanation types exemplify the notion of "spontaneous constructions." We observe the degree to which he can quickly shift ideas from task to task as well from item to item within each task. From pre- to posttest we see how he jettisons his elaborate alternative conceptions. His anthropomorphism in the first iteration of the guppy task is richly imagined. No trace of it remains in his posttest. The idea of cheetahs teaching each other Aikido technique in that item springs from what we may assume is deeply felt personal experience—he dismisses it completely in his posttest. This ease of divestiture reveals his inclination to spontaneous construction. The question raised by his conceptual instability then is to what extent it affects (or more pertinently does *not* affect) his understanding of biological processes. In other words, does B's exuberance in conversation obscure the level of his understanding? If we expand the breadth of this question to include in what way spoken language illuminates or conceals the knowledge of the speaker, we have arrived at a central inquiry of this study.

From pre- to posttest, B does show a change in the way that he maintains normative explanations. In the pretest B demonstrated a habit of accepting each question as an opportunity for new invention. For instance, in the cricket, guppy, and butterfly tasks of his pretest, B readily changes his normative idea for an alternative conception within the scope of each task. In the posttest of these tasks, however, B expresses and holds the same normative ideas (i.e., survival advantage of trait, change in distribution of traits in a population) across the set of questions within each task. It appears as though after his participation in the summer instruction there is more stability in B's normative ideas within tasks that foreground the idea of within-kind variation.

Chapter 7: The Case of W

> *"Maybe sometime in a new decade the cheetah was trying to catch its prey. And it kept trying and kept trying and it really really wanted its prey more than anything. And its leg muscle, front leg muscles and back leg muscles got stronger, and it could run faster and their babies inherited it."*

Overview

Last we have W, a student who participated in both years of the instructional course. Even prior to instruction W already displays in his first interview a set of normative and alternative conceptions. A close look at how these normative and alternative explanations respond to specific tasks highlights W's sensitivity to the context of assessment items and its impact on the elicitation of his ideas. In both years of his pre- and posttests, W's responses maintain a consistent pattern (See Tables 21 through 24). In tasks that foreground variation W could quickly and confidently express a near natural-selection explanation. In tasks that did not foreground variation, he displays more uncertainty in his explanations and cued multiple alternative conceptions that oftentimes conflicted with each other.

Because the assessment tasks in years one and two of the interviews were not identical, I am here focusing primarily on W's Year Two responses, with an abbreviated consideration of Year One, specifically those tasks that were repeated in the second year. Therefore we will examine W's Year One responses to the *Brassica rapa*, guppy and cheetah tasks. By tracking the development of these responses from Year One to Year Two, we can assess the durability of W's ideas and gain a window on how conceptions develop or change over time.

Table 21.
Year One Pretest Summary of W's Alternative and Normative Conceptions, Sorted by Episode

Pretest Episodes, Year One	Alternative Conceptions	Normative Conceptions
BRASSICA RAPA Prediction and Explanation: five generations after arrival of caterpillars		
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
GUPPY Empirical Feedback: How is this different? How do you think that happened?		
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Change in Distribution

Pretest Episodes, Year One	Alternative Conceptions	Normative Conceptions
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Anthropomorphism	
CHEETAH Dynamic Assessment: Survival Advantage of Trait		1~Survival Advantage
CHEETAH Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Survival Advantage 2~Reproductive Advantage
CHEETAH Dynamic Assessment: Inheritance, Survival and Reproductive Advantage, Distribution		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution
CHEETAH Original Question		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution

Table 22.
Year One Posttest Summary of W's Alternative and Normative Conceptions, Sorted by Episode

Posttest Episodes, Year One	Alternative Conceptions	Normative Conceptions
BRASSICA RAPA Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Change in Distribution
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Change in Distribution
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Anthropomorphism 2~External Agent	1~Survival Advantage 2~Random Mutation
CHEETAH Dynamic Assessment: Survival Advantage of Trait		1~Survival Advantage
CHEETAH Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Survival Advantage 2~Reproductive Advantage
CHEETAH Dynamic Assessment: Inheritance, Survival and Reproductive Advantage, Distribution		1~Survival Advantage 2~Reproductive Advantage
CHEETAH		1~Survival Advantage

Table 23.
Year Two Pretest Summary of W's Alternative and Normative Conceptions, Sorted by Episode

Pretest Episodes, Year Two	**Alternative Conceptions**	**Normative Conceptions**
CRICKET Prediction and Explanation: one generation after arrival of caterpillar		1~Survival Advantage 2~Change in Distribution
CRICKET Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Change in Distribution 3~Extinction
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Survival Advantage 2~Change in Distribution
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Change in Distribution
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Other: Diet	1~Random Mutation
SPARROWS Dynamic Assessment: Survival Advantage of Trait	1~Other: Diet	1~Survival Advantage
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		
SPARROWS Revoicing		1~Inheritance
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Anthropomorphism 2~Lamarckianism	
DESERT PLANTS Explaining the fit between plants and their environment		

Table 24.
Year Two Posttest Summary of W's Alternative and Normative Conceptions, Sorted by Episode

Posttest Episodes, Year Two	**Alternative Conceptions**	**Normative Conceptions**
CRICKET Prediction and Explanation: one generation after arrival of caterpillar		1~Survival Advantage 2~Change in Distribution
CRICKET Prediction and Explanation: five generations after arrival of caterpillars		1~Survival Advantage 2~Change in Distribution 3~Extinction
GUPPY Prediction and Explanation: one generation after arrival of predator fish		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance
GUPPY Empirical Feedback: How is this different? How do you think that happened?		1~Survival Advantage 2~Change in Distribution
GUPPY Prediction and Explanation: three generations after arrival of predator fish		1~Survival Advantage 2~Change in Distribution
BUTTERFLIES Prediction and Explanation: 50 generations after arrival of birds		1~Survival Advantage 2~Change in Distribution
BUTTERFLIES Dynamic Assessment: Inheritance, Survival and Reproductive Advantage		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance
BUTTERFLIES Revoicing		1~Survival Advantage 2~Reproductive Advantage 3~Change in Distribution 4~Inheritance
SPARROWS Explaining Change: How come the sparrows living in cold places today are so much bigger?	1~Anthropomorphism 2~Other: Diet	1~Survival Advantage 2~Reproductive Advantage 3~Inheritance
SPARROWS Dynamic Assessment: Survival Advantage of Trait		
SPARROWS Dynamic Assessment: Inheritance, Survival and Reproductive Advantage	1~Other: Diet	
SPARROWS Revoicing	1~Anthropomorphism	
CHEETAH Explaining change: How come cheetahs today are so much faster than their ancestors?	1~Other: Diet	
DESERT PLANTS Explaining the fit between plants and their environment	1~Anthropomorphism	

W's 2009 Pretest: Unpacking the Normative and Alternative Conceptions

In the *Brassica rapa* task of his first interview, W is asked to predict and explain what the next generation of *Brassica rapa* plants will look like after the caterpillars arrive. He lays down seven hairy plants and five smooth plants and provides the interviewer this explanation.

> W: The wind carried them into different places, so they might not be in the same places as those [points to *Brassica rapa* in original template].
> I: And what do you have here?
> W: The flowers with thorns and without thorns.
> I: So how will that happen?
> W: When the seeds come out, like they splatter everywhere. And then some animals like to eat them. Or they might get burned if they blew too high. And if they go, then they might go too low, they might be right next to the ocean. They might drown and they might go on a mountain of ice and they might die. And then some flowers might cover up other flowers so they can't get sunlight and some ones might be too big for other ones and then the big ones get all the nutrients.

W's explanation in this episode is focused on the seeds of the plants and the modes in which they disperse. He does not attend to the variation of traits in the *Brassica rapa* plants. Nor does he address the effect on the plant population of the arrival of the caterpillars. As in the case of S, his response misses the intended focus of the task. Unlike S, however, W does not rely on anthropomorphic or transformationist reasoning. His answer is not so much an alternative conception, as a *parallel* conception—a scenario that bypasses natural selection, without specifically contradicting it. The description he provides of the many ways in which a seed might fail to germinate falls within the range of normative biological ideas. That idea, however, is not connected to the environmental press in the present example (caterpillars).

W attends to within-kind variation and how a trait can confer survival advantage. In the guppy task, W is asked to make a prediction for the next generations of guppies after the predator fishes have arrived. He lays down four yellow and eight gray guppies and explains.

> W: Because the gray ones, they can become camouflage with the water because it's kind of black and like the same colors as the gray guppies. And the golden and orange ones, they can't camouflage so much, so they have to hide.
> I: So what do you have here [points to W's prediction]?
> W: The predator fish will actually see some, but they're not chasing so much gray fish because they cannot see them so good. And the yellow ones, they can see them good and they eat them and then there's less and less of them.

In this episode, we see that W attends to the variation in color of the guppies and how the gray color trait confers a survival advantage. His prediction displays a shift in relative frequency of traits, with the gray guppies more prevalent in the second generation. He explains how the gray guppies through camouflage blend into the background and are less visible to the predator fish, adding that the predator fish can see the yellow guppies easily, so they will be eaten and "there's less and less of them." He shows an understanding of the survival advantage of being gray and how that individual survival value can affect the population's distribution of traits in the next generation. In contrast to his answer to the *Brassica rapa* task, he not only recognizes the relevant features of the item, but puts them together in a coherent and scientifically valid explanation.

The interviewer then shows W "what the scientist actually saw" and asks him how the guppies in that pool are different from the ones in the pool one generation earlier.

> W: Now they're getting chased away and the other ones are trying to get away. And the predator fish can only see the gray ones.
> I: Tell me a little bit more about that.
> W: The gray fish they're enjoying their time with young ones. They're swimming all around there 'cause the fish see them so they're trying to get away.

Although his prediction is similar to the empirical feedback, W does not repeat his earlier ideas. He broaches instead a mildly anthropomorphic[2] scene of fish "enjoying their time with young ones," then brings in the predators, describing how the guppies are "swimming around" and "trying to get away." Because W can see that there are mostly gray guppies in the pool, he reasons that the predators will switch their attention to the harder-to-find fish. In this episode the camouflage advantage appears not to matter.

Making his prediction for the following three generations of guppies, he lays down 10 gray and three yellow guppies, which is a shift towards more gray and one fewer yellow from his earlier prediction. He explains the new ratio as follows.

> W: The gray fish they're not running away so much and there's more gray fish. They're not running away from the predator so much.
> I: So how will that happen?
> W: Because the predator fish they're eating the yellow fish and there's less and less and the gray fish they don't see them so much. And then the fish when they're looking they still don't see it but um, maybe the scientist might see it.

W displays a gradual shift in distribution of traits towards more gray guppies and fewer yellow guppies over the next three generations. He brings up his earlier points that the predator fish will eat the yellow guppies and there will be fewer of them, while there will be more gray guppies because the predator fish cannot see them. In this task, W reveals an understanding of the survival advantage of the gray color trait and its effect on the distribution of traits in the population of guppies.

In the next task W explains to the interviewer why cheetahs today are so much faster than their ancestors.

> W: Like when they run, they keep trying like they never did. And then it's like exercising. Then their muscle, they can, it helps them move faster.
> I: Tell me more about that.
> W: When the cheetahs, when they like run, and they never give up. And then when they run, their muscle gets stronger everyday and then they can run faster.

[2] Note that this episode was not coded for an anthropomorphic conception because although W describes an anthropomorphic scenario, he did not explicitly employ anthropomorphic reasoning to explain the change in distribution of traits.

Similar to many in his cohort, W voices here an alternative conception. He attributes to the cheetahs an anthropomorphic intention to "keep trying like they never did' and "never give up." Even when applying non-normative reasoning, however, W adheres to demonstrable biological realities. He suggests running helps the cheetahs exercise their muscles, which in turn, makes them stronger and able to run faster. His explanation combines intentionality and the change in muscle structure as mechanisms of evolutionary development.

In a short dynamic assessment item the interviewer asks, "How do you think being fast could help the cheetah?"—a question intended to scaffold the survival value of that trait—and W answers, "It could help them catch their prey." Further scaffolding the reproductive advantage of the fast running trait, the interviewer tells W, "In every generation, not all cheetahs survive long enough to have babies. Which ones do you think will survive and have babies? The slower ones or the faster ones?"

W: The faster ones.
I: And why do you think it would be those?
W: Because they might also have like, they might have some animals that like to eat cheetahs and they can run away.

Next the interviewer scaffolds the idea of inheritance and how the cheetahs that can run fast have a survival and reproductive advantage. She asks W to imagine a group of 10 cheetahs living together, five of which are slow-running and the other five fast, and asks W which cheetahs are most likely to survive and pass on their genes to the next generation. W replies, "The fast ones." The interviewer then asks W, "So what difference would that make for the number of baby cheetahs in the group that inherit a faster speed and the number of baby cheetahs that inherit a slower speed?"

W: There might be like 15 fast cheetahs and 11 slow cheetahs.
I: Tell me more about that. What do you mean by that?
W: If they are slow they might get eaten. And like if they both were the same amount, some of them might get eaten because they are not fast enough. And the fast ones, they can run away when something tries to get them.

In these dynamic assessment episodes, we see that with scaffolding, W becomes attentive to the idea of variation in a population of cheetahs. With further scaffolding, he is able to reason about the survival and reproductive advantage of running fast and how that in turn affects the distribution of traits in the cheetah population.

Returning to the original question, the interviewer asks W, "How come most cheetahs today are so much faster than their ancestors, the ones that lived a long time ago?" And W answers, "Because they got eaten and the slow ones might have gotten eaten and then there is some slow ones. And the fast ones, they survived and now there's more fast ones."

In this task, we observe how, with the aid of dynamic scaffolding, W's idea shifts from an alternative to a normative conception. At the beginning of the task, W explained how cheetahs have gotten to be faster through effort and will. He asserted, "They keep trying like they never did" and they "never give up." That effort, according to W, in turn helped them exercise their leg muscles and made them faster. After exposure to the dynamic assessment, however, W is able to distinguish the variation of speed among cheetahs and explain both the survival value of being a fast-running cheetah and its effect on the distribution of traits in a population.

Summary of W's 2009 Pretest

What are the alternative conceptions that W has about evolution? W broaches few alternative conceptions in the selected pretest tasks. Though his answer to the *Brassica rapa* item misses the intended focus of the task and fails to explain his prediction for generational change, it does not employ alternative reasoning. In the guppy task he tries out a vaguely anthropomorphic concept in response to "what the scientist saw," but quickly discards it for a normative explanation in the next episode. Only in the cheetah task do we see significant alternative conceptualization in W's pretest responses. His first answer attributes to the cheetahs an anthropomorphic intentionality to "keep trying" that would lead to muscle development through repeated exercise.

How variable or consistent are W's alternative conceptions across the range of tasks in his interview? To what extent can the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in his explanations across contexts? In contrast to those of the three other case study subjects in this analysis, W's alternative conceptions are highly subject to immediate modification through dynamic assessment scaffolding. In both the guppy and cheetah tasks his anthropomorphism gives way to scientifically sound reasoning in response to hints from the interviewer. W's method of testing his theories as he voices them predisposes him to a swift change of thinking when confronted with additional data—or simply more time to consider.

W's 2009 Posttest

After his participation in the instructional intervention, W's display of normative ideas is further in evidence in the first set of posttest tasks. When the interviewer asks W to make a prediction for what the next generation of *Brassica rapa* plants will look like after the caterpillars have arrived, he lays down 13 hairy plants and four smooth plants and explains his prediction.

> W: They're mostly thorny ones, but there's a super little bit of the not hairy ones. And even those might get eaten.
> I: So how will that happen?
> W: Because the caterpillars weren't eating the hairy ones. And they were eating the ones that weren't hairy, and they might not have finished all of it because it's a lot to finish, and I don't think caterpillars can finish that fast. And then they might start eating it again, and there might not be any.

In his pretest for this task, W did not attend to the variation of traits in the *Brassica rapa* plants. He instead explained the various modes of *Brassica rapa* seed dispersal. In his posttest, however, his prediction reveals attention both to the variation within *Brassica rapa* plants and to the effect of the environmental press (i.e., caterpillars) on the distribution of traits in the population. His prediction displays a shift in favor of hairy plants with only a few smooth ones surviving in the second generation. W explains how the caterpillars "were eating the ones that weren't hairy" and "weren't eating the hairy ones." His prediction and explanation show an understanding of the survival value of being hairy.

W's firm grasp of the survival advantage of traits continues in the task that follows. Here he makes a prediction for what the next generation of guppies will look like after the predator fish have arrived. He lays down 11 gray guppies and four yellow guppies.

> W: There's more black ones than yellow ones.
> I: So how will that happen?
> W: Because the predator fish they, this is like kind of dark. The black guppies can blend in more than the golden guppies. Then the predators can see them. And then they're getting chased from the predators. And then sometimes they might hide in the rocks so there will be a very little bit of them. And the fish can…the gray guppies will be…there will be more of them.
> I: So how does that happen?
> W: There's like the yellow ones are getting eaten because they can't blend in so good. And the gray ones can. And a very little bit might get chased from the predators. But most of them, they can survive and then they give babies. There will be more and more gray ones because they can give more babies than there, like there's this much. Like when they give babies, there might be like three times as much as this. And then the yellow guppies they'll get eaten so when they give babies, they won't have as much, and when they get eaten, there will be less and less.

W's prediction is similar to that of his pretest: In both tests he identifies the survival advantage of being able to blend into the rocks, though his posttest explanation is more elaborate, in that he also describes the reproductive advantage of being a gray guppy. Here W expresses a near natural selection explanation when he asserts the gray guppies will survive to "give more babies" thus increasing exponentially their numbers while the yellow guppies, reduced by predators, will "give" fewer babies and their population will be "less and less."

When the interviewer shows W "what the scientist actually saw," W describes to her what he sees: "There's more gray ones than yellow ones. There's only five yellow ones. And eight gray or black ones." W then makes a prediction for what the next three generations of guppies will look like. He lays down eight gray guppies and three yellow guppies and describes fhis prediction.

> W: There's only three and there used to be like five of them, I mean six of them [referring to the number of golden guppies in "what the scientist actually saw" template]. And now there's only three [yellow guppies]. And there's eight, eight black or gray guppies.
> I: So how will that happen?
> W: Because the same as I said at the first one. And then when they give babies, the babies will get eaten. And then when they try to hide, there's gonna be a very little bit, so only one guppy might survive and the other two might get eaten. And when the one gives off babies, there might be a little bit more. But there's still gonna be way more gray or black guppies. This one [points to yellow guppy] might survive and give off another three babies, but there still might not be enough.

W displays in his prediction a gradual shift in distribution towards more gray guppies and fewer yellow guppies, applying the same ideas as before to explain the shift in distribution over the next three generations. W's articulation of the survival and reproductive advantage of being gray and its effect on the distribution in the population over several generations reveals that he can apply a near natural selection explanation to the evolutionary phenomena in this task.

In the next task the interviewer asks W to explain how cheetahs today can run so much faster than their ancestors.

> W: There might be like a super tiny bit of like a little one, like fast ones. And they might be really rare. And like when, and then, if they try, their babies might be a tiny bit faster, like almost a tiny bit faster or a tiny bit slower than their parents. And then some of them might get killed from lions or tigers. And then the ones that get faster can go run away, and then they might get faster. And when Paul Williams[3], there were like slow and then he picked out and somewhere like 21 and then they came. And then after they [inaudible] it, it was the first generation, then it was only, there was like 19, and that might have happened the same to the cheetahs.
> I: So Paul Williams, it was 21 what?
> W: 21, like the Brassicas took 21 days to flower. And then 20. And then when it was the first generation, then it took 20 days for the Brassica plants to flower, and that might have happened the same to the cheetahs.
> I: So help me understand how that is the same as the cheetahs.
> W: Because maybe since the Brassica plants can flower less days, maybe the cheetahs, they are a little fast, so then their babies can go be fast, and they might. And then Brassica plants, when they grow faster maybe it is because he treats the Brassica plants better and maybe there's another animal that helps the cheetah. Or maybe not, actually, I don't think so.
> I: You said that some cheetahs run faster than other cheetahs a long time ago. So how does that explain, how does that happen?
> W: Maybe some were like, when they were made, maybe they were sick when they were just made. And then when they gave birth to their babies, they were sick because the parents were sick. And maybe like some were not sick, and like maybe this one [points to cheetah picture] is orange, and this one is kind of yellow [points to another cheetah picture], and that might mean that this one might have a sickness, because this one is a brighter color than that.

W's response to this question appears to be the most tentative answers of his Year One pre- and posttest interviews. Though his pretest movement through a series of dynamic assessment items took him from an alternative to normative conception, his posttest explanation retains only traces of that progress. He continues to show understanding of trait variation and survival advantage, but expresses intentionality in suggesting that the offspring of fast cheetahs might be "a tiny bit faster" "if they try." He then analogizes the evolutionary development of the cheetahs to Paul Williams' selective propagation experiments with *Brassica rapa* plants and briefly considers an external agent explanation of another animal helping the cheetahs get faster—an explanation he rejects immediately upon expressing it. Next he considers a scenario by which the slower cheetahs might be the offspring of "sick" parents and the faster ones were the anomalous babies

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[3] Paul Williams is a botanist whom the students met and with whom they got to chat during the instructional intervention

that were born "not sick." W's explanation here invites several ideas, such as inheritance, within-kind variation and random mutation (a concept not taught in the curriculum). He uses the cheetah photographs as evidence for his theory, pointing to the cheetahs and noting their varying brightness in color, which he believes might explain their variation in health.

When the interviewer asks W, "How do you think being fast could help the cheetah," he answers "Escape and get prey." In this part of dynamic assessment, the interviewer asks W, "In every generation, not all cheetahs survive long enough to have babies. Which ones do you think will survive and have babies? The slower ones or the faster ones?"

W: The faster ones.
I: Why do you think those will be the ones that survive?
W: If there's like their predators, their predators might try to catch them. And the faster ones can escape.

The interviewer scaffolds to W the idea of inheritance, and the survival and reproductive advantage of running fast. She asks W, in a group of 10 cheetahs where half are slow-running and the other half fast, which ones are most likely to survive and pass on their genes to the next generation? When W answers, "The faster ones," the interviewer follows up with another question, "So what difference would that make for the number of baby cheetahs in the group that inherit a faster speed and the number of baby cheetahs that inherit a slower speed?"

W: Like maybe, when the predators come while they're a baby, they might eat them. And then the little group, their parents might protect them. And if they can't, maybe the babies will try to hide or the parents might carry them, and then they'll hold tight.

From his series of answers in the dynamic assessment episodes, W shows an understanding of the survival advantage of being a fast-running cheetah. In his response to the last question, he does not mention the gradual change in distribution of traits among the cheetahs, which is the intended focus of the item, and instead describes a scenario of baby cheetahs protected by their fast-running parents. When the interviewer returns to the original question, W is silent. Sensing his discomfort in answering the question again, the interviewer moves on to the last part of the task. She reads to W "what another student said" and asks W to explain what the student meant by his explanation.

W: Maybe he meant like when they bring food, maybe like their muscles might get stronger because they'll [inaudible]. Like the slow ones couldn't bring food, enough food for the small ones that weren't fast, so their muscles couldn't be so strong, so they couldn't run so good, and then it started happening the same way for generations and generations.
I: So how could that explain how cheetahs today are so much faster than the ones from before?
W: Like maybe, like antelope, or maybe the fast ones could catch some. And then the meat would make their muscles stronger. So and then they could run, and maybe they would bring some fruit to give them vitamins.

W offers an interpretation of "what another student said" that differs from the natural selection explanation. He articulates a circular logic, where the "the slow ones couldn't bring food" to "the small ones that weren't fast, so their muscles couldn't be so strong, so they couldn't run so good." This process, W explains, would continue "for generations and generations."

2009 Posttest Episodes Summary

How do W's alternative conceptions change or persist after his participation in an instructional course that scaffolds the conceptual underpinnings of evolution? And to what extent can the contexts account for the variability in W's explanations across contexts?

W's posttest explanations reveal a mix of progress (in the *Brassica rapa* and guppy tasks) and regression (in the cheetah task). While in the pretest of the *Brassica rapa* item, W misses the intended focus of the question entirely, in his posttest he articulates a near natural selection explanation. In the guppy task he builds upon his normative pretest response to include the reproductive value of camouflage and its effect on the distribution of traits in the population. It is in the cheetah task that we see W expressing less coherent and normative ideas. Despite an ability in the pretest to articulate a natural selection explanation (after the dynamic assessment scaffolding), in the posttest W voices several alternative conceptions, including anthropomorphism and external agency. He attempts to link the idea of artificial selection (which was exposed to in the instructional course) to the case of the cheetah but struggles to explain the mechanism through which the cheetahs get faster over time. He also mentions an idea that sounds like random mutation to explain how within-kind variation may appear in the population. W is less certain about his explanations and instead of offering a single coherent idea as he did in the previous two tasks (i.e., *Brassica rapa* and guppy), he expresses many that seem tentative and mixed.

If we are to seek an explanation in the pattern of W's mixed responses (and in his two-steps-forward-one-step-back progress from pre- to posttest), we may find it in the theory-building nature of his reasoning. Consistently throughout both tests, W applies a piece of practical knowledge of the natural world and his own capacity for logical inference to answer the questions. In the pretest *Brassica rapa* item, his scenario of seeds dispersing in various places misses the intended focus of the task, but is nonetheless grounded in principles of botany. His observation of the advantage of camouflage in evading predators in the guppy task again adheres to a practical concept of nature's dynamics. Even in his anthropormophic characterization of cheetahs with a never-give-up work ethic, W connects a practical fact: that exercise builds muscle and makes a body stronger. After the instructional intervention, W's answers continue to reflect this habit of applying what he knows to what he is asked. In the posttest he gives a near natural selection explanation to the *Brassica rapa* item. In the guppy item, he expands on his earlier answer to infer a reproductive advantage in protective coloration. Only in the cheetah item does he fail to maintain a steady trajectory toward improved understanding. Yet even as W loses his grip on the natural selection explanation that he was able to give after some scaffolding in the pretest, we can see him applying his own method of reasoning as he tries and rejects a variety of alternative conceptions.

W's 2010 Pretest

Because W participated in both the 2009 and 2010 interviews, his case offers a unique opportunity to assess the endurance of his ideas and to test in what way alternative or normative conceptions persist or change over time. While the first question of his 2010 pretest, the Kauai crickets task, is one he did *not* address in 2009, it is isomorphic in structure with the *Brassica rapa* item with which he began the prior year's interviews. There the focus was on what effect a single trait variation (hairiness) had on the population of plants in the event of an environmental press (caterpillars arriving and eating the hairy plants). Here the trait variation is the ability to chirp and the environmental press is the arrival of flies laying eggs in the crickets' bodies. The evolutionary dynamic is in both cases the same.

In his prediction for the next generation of crickets on the island of Kauai, W lays down 12 mute crickets, and two chirping crickets. He explains his prediction for the next generation of crickets to the interviewer.

> W: There will be more male flies that couldn't chirp.
> I: Can you explain how that will happen?
> W: Because the blue [referring to the border color of the mute cricket icon] can't chirp and the red [referring to the border color of the chirping cricket icon] crickets can. And the fly hears the crickets, he or she lays the eggs on the crickets that can chirp.
> I: How will that happen?
> W: Because the crickets will lay their eggs in the crickets that do chirp and they can hear the sound and go to that one. The blue-card crickets, since they don't make sounds, like they don't make any sounds, the flies can't hear them.

Asked to predict what the following five generations of crickets will look like, W lays down 16 mute crickets and two chirping crickets and explains his prediction.

> W: There will be more blue crickets than less red cricket-cards. I think the red crickets will be critically endangered.
> I: How?
> W: Because in one year later when there were a lot of red crickets. Then one year later the flies come and ate the red and, I mean they lay the eggs and the eggs killed the crickets that could chirp. And then five years later there'd be only like two of them. Maybe in like two more, three more days they might be extinct.

In this task, W displays an understanding of the survival advantage of being mute and how it effects the population over a single and multiple generations, taking it to its logical conclusion: eventual extinction of the chirping crickets.

With the guppy item we have our first chance to observe how W's strong performance in Year One cohort carries over to Year Two. In his prediction for the next generation of guppies, he lays down 11 gray guppies and six yellow guppies, explaining his prediction.

> W: The dark guppies camouflage better in the pool because the rocks in the water are dark, they're light gray, and the guppies blend in.
> I: So how will that happen?
> W: Because the predator fish ate all the yellow guppies because they were easier to spot.

When the interviewer shows him a template of "what the scientist actually saw," W explains why there are more gray guppies than yellow guppies, "These guppies can blend in with the rocks. The black, dark guppies are blending in and the yellow guppies aren't." W then makes his prediction for the next three generations of guppies, placing 12 gray guppies and three yellow guppies on his template.

W: Last time [in the second generation] there was 10 guppies and there are [starts counting the guppies in his prediction] 13 guppies.
I: 13 total guppies?
W: Ya. No, 13 black guppies.
I: And you mean last time, this time [points to empirical feedback template]? There was 10?
W: Ya, there was 10 dark guppies and now there's more and less yellowish guppies.
I: And how did that happen?
W: Because the predators, there'd be more. They were still eating the yellowish ones.

W expresses ideas that are similar to his previous set of interviews for this task. He articulates the survival advantage of camouflage and how that translates to a change in distribution of traits on a population level. He offers no hint of the anthropomorphism, which he mentioned in his Year One pretest answer to this question. His conceptual surety appears to have strengthened from one year to the next.

Next the interviewer asks W to choose one of four templates that shows what he thinks the Banded Peacock butterflies will look like 50 years after the birds that attack them arrive.

W: I know these two for certain [points to template 1 and 2] I think are not. But [points to template 3 and 4] one of these are maybe.
I: You think it's one of those?
W: I think it's one of these.
I: And how did that happen that it went from looking like this [points to original template] to 50 years later looking like that [points to template 3 and 4]?
W: Because there's like caves and these butterflies can blend in?
I: Which butterflies can blend in?
W: The black ones. And the green ones, they try, like the stripes of their wings will blend into the grass but the rest of their body, the white dots, they can kind of blend in but not so much.
I: So how would it happen that it go from looking like eight green-striped butterflies for every two to eight plain ones for every two or no striped ones?
W: Maybe the birds' eyesight. Maybe they can only see like certain colors, like green or others, like they can't see every color, like the black and the blue, they couldn't see the difference or maybe the green and blue and black they can see the difference.
I: And what would that do? If they could see the difference?
W: They can, it would be easy, to eat the butterflies that have the green stripes.

W again displays a natural selection explanation, and he also considers the context in which the green-striped wing trait may have a survival value, asserting, "And the green ones, they try, like the stripes of their wings will blend into the grass." He then reasons on a technical level how the black wings of the butterflies can help them camouflage against the blue sky (on the template, the butterflies are shown against a blue background). Finally he speculates on the birds' inability to discern these two colors (black and blue), which ultimately explains how the black-winged butterflies were able to survive. In these answers we again see the hypothetical quality of W's reasoning. He is not content to accept the task prompt “the birds like to attack the striped-wing butterflies” as is. He seeks to understand how and why.

The interviewer asks W to explain how the sparrows that live in cold places today are so much bigger than the ones from 100 years ago.

> W: Maybe something went wrong with the bird, one bird, and their bone got too big and then they had babies and started making those ones. There was like maybe in cold places something can happen to a bird’s body and their bones got bigger. And in warm places the sparrows are more used to the warm places and nothing goes wrong. I don’t really know if it’s true, but maybe. Maybe these [points to warm places template] like they’re different sizes, maybe they didn’t grow too much bigger. Maybe like these [points to 100 years ago template] some of them are different sizes and some, they got a little bigger. Maybe they eat more food. They have a bigger diet than the birds in the warm places because the birds in the cold places, maybe they need more food to survive.

W expresses two ideas in this episode. His first suggests that random mutation occurred among the sparrows that lived in cold places as opposed to those in warm places. This concept that “something went wrong with the bird” echoes W’s Year One speculation in the cheetah task that “sick” parents might have given birth to “sick” babies. Here the birds with abnormally big bones pass on that trait to their offspring. W’s second idea suggests that the bigger birds had a “bigger diet.” In the following episodes we will see how of the two ideas, he favors the “bigger diet” idea.

When the interviewer scaffolds the concept of survival advantage of the larger body size trait to W and asks him the original question again, W replies, “Maybe they have to, they really need to eat fat to stay warm because my friend, who is a little bit more chunkier than me, and when he goes swimming, he always stays in the cold like the longest. He doesn’t get cold.” W here carries over his “bigger diet” idea from the previous episode and adds an experiential analogy. He compares the bigger sparrows to his “chunkier friend.” Both his bigger friend and the bigger sparrows eat more and can stay warm longer in cold places. Once more, W applies personal observation, his own knowledge of his friend, to the problem at hand.

The interviewer scaffolds the concept of inheritance, survival and reproductive advantage of trait to W and asks him the original question again. W responds, “Well maybe the birds were born in a different way. Because some people are short and some people are tall. Maybe some birds are chunky and some birds are more thin. And maybe that’s just the way they were.” Here W expresses the idea of inheritance and within-kind variation to explain how some sparrows are born bigger than others. He analogizes the size of birds to the varied height of humans, which was an example used in the dynamic assessment of this task to scaffold the concept of inheritance (e.g., “…just like tall parents have children that grow up to be tall”).

The interviewer reads to W “what another student said,” which is the natural selection explanation. She then asks W to explain and evaluate this student’s explanation.

> W: I think he meant, I think he’s kind of right, I think he meant that when the birds, when the bigger birds migrated over to the cold places and they couldn’t find their way back or something. And the bigger birds, the bird that inherited their parent’s. I think the part where he said that the birds inherited the chunkiness of the parent was true. I think that he was right that they inherited the chunkiness.

I: And why do you think he was right?
W: I didn't think that, but now I just thought about it, and he said that they inherited the chunkiness of their father and mother and I didn't think about that. And now when I think about it, I agree with him. Maybe for some reason, the hot weather birds make them smaller. I don't know, but maybe.

W agrees with the student's explanation, yet he interprets it to mean that "the bigger birds migrated to the cold places and they couldn't find their way back." He interprets correctly the idea that sparrows inherit their size or "chunkiness" from their parents. The natural selection explanation prompts W to consider the idea of inheritance, with which he agrees.

The interviewer asks W to explain why cheetahs today can run so much faster than their ancestors.

W: Maybe sometime in a new decade the cheetah was trying to catch its prey. And it kept trying and kept trying and it really really wanted its prey more than anything. And its leg muscle, front leg muscles and back leg muscles got stronger, and it could run faster and their babies inherited it.
I: Inherited what?
W: The strong legs.

One year later W returns to his original concept of cheetahs not giving up in pursuit of their prey and a resulting improvement in their muscle structure. Here he expresses an anthropomorphic idea that "in a new decade" the cheetahs tried "really hard" to catch their prey. The effect of their effort and wanting "its prey more than anything" made their front and back leg muscles stronger. He adds that the offspring inherited the strong legs from their parents. This is the first instance in which W expresses a Lamarckian idea. His explanation includes both the idea of "use vs. disuse," where use of an organ can change its structure, as well as the idea of soft inheritance, where the offspring inherits its parent's acquired traits.

Completing the pretest, the interviewer asks W to explain how plants can fit so well to where they live.

W: Like maybe the offspring, like the seeds, would get blown way. And one time the seed would get, the wind would [inaudible] it up to the desert and when the plant grow up, maybe the wind wouldn't be as strong as it would in other places and it would blow it like the middle of the desert or the sides of the desert but not outside of the desert."

He adds, "Weeds can grow anywhere, well maybe not in Antarctica or the South Pole or the north pole. But there's lots of them and they don't need much to grow, just like tiny microscopic things, that they can travel." Reprising his *Brassica rapa* explanation in his Year One pretest, W here ignores the mechanisms of natural selection and instead describes how the seeds of plants can get blown into the desert by the wind. However the wind, according to W, will settle eventually and the seeds are only blown within the parameters of the desert. As a possible explanation why plants fit so well where they live, he offers an analogy to weeds, which can grow anywhere because their needs are limited.

Summary of W's 2010 Pretest

What are the alternative conceptions W has about evolution? W repeats alternative conceptions he brought up in the Year One interviews including random mutation (in the sparrow task) and anthropomorphic intentionality (in the cheetah task), and introduces a new idea, Lamarckianism (in the cheetah task). Also of interest is the alternative conception from Year One he does not repeat here: the external agency idea with which he struggled in the first year posttest cheetah task. While he repeats the concept of cheetahs "trying hard" to catch their prey and thus becoming faster, he appears to have rejected conclusively the notion of external help from another animal.

How variable or consistent are W's alternative conceptions across the range of tasks in his interview? To what extent can the contexts, or the phenomenal settings of the assessment tasks, account for the consistency or variability in his explanations across contexts? In the second year of his pretest, W continues to express normative natural selection ideas in the *Brassica rapa*, guppy, and butterfly tasks. However, in items where within-kind variation is not salient and W is prompted to explain change in organism-kind or the adaptation of organisms, he expresses multiple alternative conceptions.

The variability of these alternative conceptions, the swiftness with which he tests and rejects them, is notable here. Unlike J and S, who return to established alternative conceptions across a range of prompts—J teleologically, S anthropomorphically—W reveals a willingness to abandon concepts that do not stand up to his own critical scrutiny or to additional data. In the sparrow and cheetah items we see him consider a variety of possible explanations with no strong commitment to any of them. In the cheetah item this method of reasoning leads him, after expressing a sound normative conception in his Year One pretest, away from his natural selection conception. His skeptical approach to interpreting evolutionary phenomena may account for the high degree of variability in his set of alternative conceptions.

W's 2010 Posttest

The analysis for W's final interview begins with his prediction for the next generation of crickets on the island of Kauai. He places 11 chirping cricket icons and six mute cricket icons down on his template.

> W: There will be 11 crickets. There will would be six pictured crickets, the non-chirping crickets and there's two extra crickets.
> I: So you think there will be two more of the non-chirping crickets than previously?
> W: And minus two chirping crickets.
> I: So how will that happen?
> W: Because the crickets, like when I go camping, if it was the same, the crickets can disappear really quickly because they chirp, where I go camping, they chirp almost every night.
> I: So they can disappear quickly. Can you explain what you mean by that?
> W: Because when the flies, if the flies had a good sense of hearing and not even if they don't, they, the crickets chirp in a group almost every night so if the flies have, which are from California, lay a lot of, if they need to lay a lot of eggs, it would be very easy to find some crickets that they need for the maggots to eat.

W displays a very gradual shift in distribution. He adds two more mute crickets and takes away two chirping crickets in his prediction for the next generation. He relates this prediction to his experiences from camping, where the crickets chirp so loudly every night that flies, were they present, would have no trouble finding hosts for their eggs. He suggests that under such circumstances the crickets would "disappear really quickly."

In W's prediction for the following five generations of crickets, he lays down 11 mute crickets and eight chirping crickets. The interviewer asks W if the seventh generation will be the same or different from the second generation.

> W: Different. I have 11 non-chirping crickets and eight chirping crickets.
> I: Okay, and how do you think that will happen?
> W: Because one generation later they already lost 3% out of 15% already.
> I: What do you mean, 3% of what?
> W: Like 15 minus, like out of the sample, they lost 3 in the first generation when the flies came. Now I think they would lose more.
> I: How would they lose?
> W: Because the same thing would happen like in the first generation.
> I: Which was what?
> W: When the flies hear the crickets every night chirping in a group, I mean evening.

W displays in his prediction a greater shift in distribution of traits over the following five generations. He explains to the interviewer the iterative and gradual die-off of chirping crickets over one and several generations.

Moving next to his final consideration of the guppy task, W lays down ten yellow and six gray guppies to explain what he thinks the pool will look like one generation after the arrival of predator fish.

> W: Well there used to be 14 guppies, and what I predict there's gonna be two less guppies and two dark guppies more.
> I: When you said two guppies less, what kind of guppies?
> W: Um the bright.
> I: Oh two less bright guppies and two more…
> W: Black guppies. Like, and um the guppies they change. But I mean their life changes, but the yellow guppies couldn't disappear that quickly in one generation, just one. They're gonna have one offspring one time, like if they have one offspring, that'll be one generation later so they can't disappear that quickly.
> I: So how will it happen that it went from looking like this to looking like that?
> W: Because the predator fish didn't eat the guppies quickly. They can't eat them all, like they can't be completely opposite in one generation.
> I: Completely opposite, what do you mean by that?
> W: So like there's more guppies in this picture [points to generation one template] and there's 14 yellow guppies so it can't be completely opposite in one generation.

Here W explains how the shift in relative frequency in traits is a gradual process. He argues that a complete shift in distribution of traits cannot occur in just one generation. He asserts that the predator fish cannot eat all of the yellow guppies in one generation and in that time the yellow guppies will have offspring. His near natural selection explanation also reveals his understanding of the survival advantage of being gray and the idea of inheritance of color from parent to offspring.

The interviewer shows W a pool template of "what the scientist actually saw" one generation later, and W explains to the interviewer the difference he sees between generations one and two.

> W: There's more dark guppies than, there's not much, wait [starts counting the guppies in generation 2]. There's more dark guppies than bright guppies and the predator fish eat the guppies very quickly I think. They eat them more quickly than I thought. And so I think that's why there's more dark guppies because they can blend in. There's these dark gaps in the picture [points to generation 2 template], so the dark guppies can go in those gaps and they can be invisible to the predator fish in a wink.

W notices how the pool "the scientist actually saw" is different from his own prediction in that the change in distribution of traits is more dramatic than his own. He maintains his explanation of the survival advantage of being gray as a reason for the shift, but the evidence causes him to alter his next prediction. Looking ahead to what the following three generations of guppies will be, he lays down 12 gray guppies and three yellow guppies.

> W: Well when I did my other prediction, it was more different than I thought. So there are five guppies [referring to number of yellow guppies in generation 2 from "what the scientist saw"], so I think there would be less guppies the next time the scientist saw it. And I think and when I didn't predict that much dark guppies, so I think there will be more dark guppies quicklier.
> I: What did you mean when you said you didn't predict that much dark guppies?
> W: Because when I did my prediction, there was less than nine dark guppies. But now I see that there was more. So I have, so I had a different way of predicting this time.
> I: And how do you think it will go from looking like this to looking like that?
> W: Because the yellow guppies would get eaten and the darker guppies are more safe to have offspring.
> I: Can you tell me a little more about your idea?
> W: Well the predator fish can ate the guppies very quickly because in the first picture there was about 10 yellow guppies and there was about three or four dark guppies and then the next generation there was only about five guppies and the rest was dark guppies.

W makes his prediction by adjusting his scale of change in distribution according to that of "what the scientist actually saw." He now believes that the shift in distribution of traits would happen "quicklier." In the guppy task, W has a near natural selection explanation for change and his prediction and explanation show a sensitivity to the rate in which the change of distribution of traits occur, as well as a readiness to adjust his thinking on the basis of new data.

In the next task, the interviewer asks W if one of four templates depicts what the Banded Peacock butterflies will look like 50 generations later, after the birds that attack them arrive. W points to the third template, which displays eight black-winged butterflies and two striped-winged butterflies.

W: I think there will be more black butterflies than the striped black butterflies. I don't think they can be extinct, but they will be critically endangered.
I: How do you think that will happen?
W: Because 50 generations later is a long time and since the bird can kill or hurt the butterflies one hundred times a year. And if they are really really desperate and or maybe even more. So if it's like 50 generations later that's a long time.
I: So you think in 50 generations it can go from looking like this to [points to original template] looking like that [points to template 3].
W: I think it could be completely opposite.

W predicts that in 50 generations, the distribution of traits in the butterfly population can shift from being mostly striped-winged to being "completely opposite" and mostly black-winged. After the interviewer scaffolds the concept of inheritance and the survival and reproductive advantage of being a black-winged butterfly, W evaluates his original prediction.

W: Well that makes it, that makes me think now I'm more sure that the black-striped butterflies would survive. I mean just the black butterflies would survive. Because first of all, all of the birds that ate the butterflies, which look like a sparrow, I mean a robin, would damage them or kill them. And on top of it, they couldn't lay offspring.

The interviewer's dynamic assessment hints about inheritance and the survival and reproductive advantage of being a black-winged butterfly make W more certain that his prediction is a close depiction of what the population of butterflies will look like 50 generations later.
The interviewer reads to W "what another student said," and W revoices and evaluates the explanation.

W: [nods] What I mean.
I: So what do you think that kid meant?
W: He meant that like if it started off like that [points to original template], it can surely not be like this [points to template 1] because that would be like no birds would attack, it would for sure. For sure it would be this [points to template 2] and I think it's this [points to template 3]. And I think the other kid meant, I think he means that if the, since the butterflies, the black ones, inherit the black from their parents, there is more of a chance for them surviving. And if the black butterflies lay a lot of eggs, that's also another reason that there can be more black butterflies than green-striped butterflies.
I: Do you think that kid was right or wrong?
W: Right.
I: How come?
W: Cause it's kind of the same explanation as mine.

Here we witness the pride of a young scientist asserting the primacy of his own theory: "It's kind of the same explanation as mine." In revoicing the natural selection explanation, W maintains the connection among the ideas of survival and reproductive advantage of being green-striped and its effect on the distribution of traits in the population. In both the pre- and posttests for this task, W demonstrates a coherent and sophisticated natural selection understanding in his explanation for his predictions.

Again tackling the sparrow task, W provides the interviewer several reasons why sparrows living in cold climates today are bigger than sparrows that first arrived in the United States a hundred years ago.

> W: Well maybe the birds split up. And some of the birds and like the bigger birds found the cold place and the smaller birds found the warm place. And then this one [points to sparrow in warm places template] looks almost the same as that House Sparrow [points to small sparrow in 100 years ago template]. So these ones got cold there so they couldn't make it in the snow because they weren't prepared. So they tried to, and they kept on going back and forth and they got more used to it. And this one [points to sparrow in cold places template] is just about as big as this one [points to big sparrow in 100 years ago template] so they stayed the same size and like maybe some grew a little bigger just because they inherited it from their parents. Like this one [points to sparrow in cold places template] might have, is a little smaller than this one [points to another sparrow in cold places template] so like the smaller one might have inherited it from its parent. Because like maybe medium and big went to the cold place and small ones went into the warm places. And so they exercised a lot so they got more used to it and stayed there. And they had all, and they started getting used to the feeling and they liked it. They might have gotten cold. They got so cold they might have started eating more food and got bigger and bigger. And that's not all that made them bigger, they might have needed food because it was cold. And the birds in the warm places, they didn't need as much food. Because the cold made the birds house sparrows in cold places want to eat. And also it maybe, wait, actually these birds [points to the warm places template] were exercising so they got smaller than those birds [cold places template] because maybe they were exercising. These birds [points to cold place template] were not exercising at all. They were just, they rest and eated the whole time.

W comes up with many possible reasons why sparrows living in cold climates are bigger than the ones from 100 years ago. His first explanation is that the sparrows "split up," with the smaller going to the warm place and the larger to the cold place. He speculates that those that went to the cold place migrated back and forth until they got used to the cold. He mentions how the sparrows might have gotten bigger because they inherited size from their parents—though his comment is too ambiguous to categorize as normative or non-normative. Does he mean the offspring inherited a genetic disposition to size or does he mean they inherited the parents' acquired size or does he mean something else? W also suggests that the sparrows in cold places might have needed more food and thus grew bigger from eating more. Conversely the sparrows in warm places might have needed less food and remained smaller due to diet and exercise. W's many ideas explaining the increase in the sparrows' size reveal both his uncertainty and his capacity for rehearsing multiple possibilities. But his explanations here are not as concrete as his explanation for the previous Banded Peacock butterfly task.

The interviewer offers W a dynamic assessment hint about the survival advantage of having a larger body size. She then repeats the original question.

> W: Well so the big birds might have gone to cold places because they didn't get cold maybe the little birds followed them but when it was too cold for them and they went back. And the big birds didn't, maybe they didn't get cold there.

After the first dynamic assessment hint, W comes up with another explanation. He reasons that all the sparrows traveled to the cold places, but that the small ones went back because it was too cold, while the big ones stayed because they did not get cold there.

When the interviewer scaffolds to W the concept of inheritance and the survival and reproductive value of being larger in body size, he offers another explanation, "Well maybe their parents ate more and sometimes like they can just be bigger than their parents like just the way they were born. They kept getting bigger and bigger and they were eating more." W's explanation has a parent-to-offspring transformational tone as he argues that the offspring of the sparrows can be bigger than their parents when they are born. He also adds that the parents ate more. It is unclear if he believes that the offspring inherited the acquired size of the parent.

The interviewer reads to W "what another student said," and W evaluates this student's explanation.

> W: I think he meant that the smaller ones had babies and got smaller and smaller over time and the big ones the babies couldn't survive cause they didn't have any feathers to keep warm. Like only if the mothers were really talented to get lots of warm stuff for the babies.
> I: Do you think this kid was right or wrong?
> W: Right.
> I: How come?
> W: Because it makes sense to me.

W agrees with this student's explanation but his interpretation of it is idiosyncratic. He reasons that the smaller sparrows bore smaller offspring and the big sparrows couldn't survive unless "their mothers were talented to get warm stuff for the babies."

Moving on from the sparrows, W explains to the interviewer his rationale for how cheetahs today are able to run so much faster than their ancestors.

> W: Maybe there was a new kind of animal that came that was the prey of the cheetah. And it made their muscles stronger so they can run faster and also maybe they kept on trying and trying and that also made their leg muscles more muscular.
> I: So how did it change from the ancestors from a thousand years ago to today?
> W: Well if it was one generation later when the animal arrived it became the cheetahs' favorite food. One generation later when the animal came, if it can run 20 mph, then maybe they can run 21 or 22 mph the next generation if the animal did come.
> I: How would that happen?
> W: Well like if the animal didn't come, if I was wrong, maybe the cheetahs got ran after by the antelope or something and they got lost and then they gave some kind of call or something to the other cheetahs, and a different animal there and they started eating that animal, like it could be a musk ox or it can be sheep or some animal.

As in the sparrow task, W comes up with a list of possible explanations. He reasons that a new type of prey might have required the cheetahs to run faster thus making their muscles stronger. He suggests a generation by generation increase in speed and adds that if the new prey didn't come, then maybe the cheetahs got chased by antelope into an area where they ate a "different animal." It is interesting to note that repeated considerations of the cheetah question take W farther and farther away from the near-normative response he gave in his first year pretest. In both this task and the sparrow task that precedes it, W's uncertainty opens his thinking to multiple alternative conceptions that appears random.

Ending at last W's fourth and final interview of the study, the interviewer asks why plants fit so well to where they live. W provides her the following scenario.

> W: Maybe a long time ago they weren't fit well where they lived and it was a disaster. And then there was offspring and it traveled far away. But it didn't get to the place where it wanted to. And then the next generation it went farther and farther until it came to the right place and then maybe the seeds changed or something. And it stayed in the desert or in the rainforest or where ever.
> I: You said the offspring would travel?
> W: Ya travel and travel.
> I: How would it do that? Can you tell me more about that?
> W: Well maybe, I heard that every five years like there's weird weather. Like this year is one of those five years. Like it's summer, it rains and it was really windy, so the plant went to the place where it landed.
> I: And you said it would travel until it got to the right spot?
> W: Ya.
> I: How would it know that?
> W: Well it wouldn't completely know it. Like maybe it traveled from the rainforest to the savannah to the desert and it wouldn't quite know it, the right place. But it would just stick its roots and tried to survive and then it would find out its strategies would help the plant survive.
> I: Mmm. Strategies?
> W: Yeah, or maybe there was some kind of spore and it came from far away and the wind can carry it very easily. And it wasn't cactus and when the cactus formed it didn't make offspring the same way as it came to be.

W's explanation takes the form of a narrative. He describes how a long time ago plants did not fit where they live. Their offspring traveled far away. He anthropomorphizes the plants when he asserts that the offspring "didn't get to the places where it wanted to." The next generation, according to W, "went farther and farther until it came to the right place and then maybe the seeds changed or something." His explanation suggests a transformational change when he asserts that the "seeds changed." When the interviewer prompts W to explain how that would happen, W continues to anthropomorphize the plants asserting they "wouldn't completely know" that they got to the right place. The plants "would find out its strategies [that would] help the plants survive." W formulates another idea of how plants became adapted to their environment. He describes how a spore was carried by the wind and "it wasn't a cactus and when the cactus formed it didn't make offspring the same way as it came to be." His explanation suggests the idea that a non-cactus plant had offspring that became a cactus and thus more suited to its environment.

2010 Posttest Episodes Summary

How do W's alternative conceptions change or persist after his participation in an instructional course that scaffolds the conceptual underpinnings of evolution? And to what

extent can the contexts account for the variability in W's explanations across contexts? One of the stated purposes of this study is to measure the variability of alternative conceptions, to determine how they change or persist in the face of instruction. Because we are able to track his responses over four interview sessions on either side of two intervening instructional courses, W's case gives us perhaps a more complete view on this issue. The results are mixed.

In contexts that foreground variation W is able to arrive at near natural selection explanations and to build on acquired knowledge to develop increasingly sophisticated responses over a two-year period. Absent this foregrounding, in contexts calling for explanations of long-term change, W reverts to alternative conceptions and in one case (that of the faster-running cheetahs) drifts away from a scientifically sound response in his first interview to a variety of alternative explanations in subsequent cuts at the question.

Given the difficulty students across the cohort demonstrate when answering the sparrow and cheetah questions, W's conceptual instability here is remarkable only in its resistance to mitigation. In the cricket, guppy and butterfly items, W's early command of principles underpinning natural selection grows stronger each time he addresses them. In the cheetah task the reverse is true. After initially arriving at a normative explanation, his retreat into anthropomorphic and Lamarckian conceptions in three successive attempts at the problem points strongly to contextual pitfalls in the task. That a student as consistent in his reasoning as W continues to give tentative and unstable explanations after two courses of instruction and a series of dynamic assessment exercises begs for closer examination of features in the task that may account for this destabilizing effect.

One such feature is the typological nature of the task—a characteristic it shares with the sparrow task which also prompted high variability of alternative conceptions from W (and from the cohort as whole). In these tasks, trait variation among organisms at a fixed point in time is either not mentioned (i.e., cheetah task) or not prominently highlighted (i.e., House Sparrows task) in the stem of the task. Thus, when W is asked to explain how an organism-kind has changed in relation to its ancestors, the burden is on him to introduce the idea of within-kind variation in his explanation. Many of the students in the cohort appeared to answer the question according to the information that was given (or not given) to them and their assumptions thereof (e.g., cheetahs today are fast and their ancestors were slow). Thus, a possible explanation for the low gains in these tasks is that they asked a typological question, prompting students to respond accordingly with a typological explanation, when, in fact, the normative response was a population-based explanation.

Allowing for the contextual split we see across the cohort—progress in the early tasks, less progress in the later—W's consistency from year to year is worthy of mention as an indication of the impact elementary school instruction may have on a student's ultimate understanding. Clearly he provides only a glimpse at this issue, but the fact that, in W's case, conceptual gains strengthen rather than erode over time lends support to one of this project's key assertions: that teaching young children fundamentals of evolution may establish a framework on which to build more advanced comprehension in years to come.

Chapter 8: Conclusions and Implications

This research explored the nature of early elementary students' alternative conceptions about evolution. By analyzing 60 sets of pre- and posttest interviews administered to second and third-grade students, this study identified the types of alternative conceptions young children have about evolution. It determined whether those conceptions were consistent or variable across a range of interview items and assessed the role of context in accounting for the patterns that emerged. The study also evaluated how students' evocations of alternative conceptions declined or increased after participation in an instructional course that scaffolded the mechanism of natural selection through cases of microevolution. The analyses of the four case study students, whose pre-and posttest patterns were representative of the two cohorts, provided a detailed within-subject look at how these alternative conceptions occurred in the context of the interview items and how they changed from pre- to posttest.

The conclusions in this chapter are organized around the research questions that guided this study.

What Are the Alternative Conceptions that Young Children Have About Evolution?

The study found that children in this project harbored alternative conceptions closely related to those identified in studies conducted on high school and college-age participants. Categories of alternative conception familiar from the literature —anthropomorphism, teleology, external agency and Lamarckian reasoning—appeared in the student responses to interview questions. Two additional categories, until now not identified in the literature, emerged as well: parent-to-offspring transformationism (PTOT)— a process by which the traits of organisms change over time and where the organism bears offspring that are more suited to its environment—and cyclical conception, a belief about the shift in distribution of traits occurring in cycles.

The presence of these six categories in student's explanations from two cohorts over a two-year period and across a range of tasks establishes in elementary-level thinking continuity with common alternative conceptions observed in later years. The inference to be drawn is that the difficulty many adults experience in comprehending and articulating how evolution works has its roots in naïve conceptions that develop at an early age. These findings support the link that has been suggested (Evans, 2008; Sinatra et al., 2008) between the cognitive biases (e.g., anthropomorphism, teleology, essentialism) that have been found in preschool children's reasoning about the biological world and the alternative conceptions that have been observed in adults' explanations about evolutionary phenomena.

How Variable or Consistent Are Children's Alternative Conceptions Across the Range of Tasks in an Interview?

The analysis of this study also explored two differing perspectives of the nature of students' knowledge structures (i.e., knowledge-as-theory vs. knowledge-as-fragments) surrounding evolutionary reasoning. The findings documented a pattern of variability among the majority of students' responses, with many showing a tendency to shift from one alternative conception to another within the confines of one interview. These findings may be viewed through and supported by diSessa's (1993) knowledge in pieces (KiP) framework. In the KiP hypothesis, students' expressions of their alternative conceptions are understood to be shifting because they are constructed in direct response to the particular characteristics of the phenomenon and questions in the interview tasks. Thus, students' explanations may not be a reflection of an existing coherent naïve theory but could be considered what Southerland and his colleagues (2001) would describe as "spontaneous constructions." According to diSessa's theory (1993), students construct understandings and generate explanations based upon the p-prims activated by specific cues in a particular context. Under this model, students are believed to be reasoning not from the basis of a naïve conceptual framework about a particular topic, but rather from core intuitions. The spontaneous nature of explanations based upon activated core intuitions could account for the variability and shifting patterns of response observed in this study. The four case study participants additionally demonstrate in their posttest results that students may form scientific conceptions *alongside* their spontaneous constructions, thus supporting diSessa's (1993) multifaceted description of how children learn.

To What Extent Can Context Account for the Patterns That Emerge in Students' Explanations?

The high degree to which certain assessment tasks tended to elicit specific explanation types suggests that the contexts of these tasks have considerable effect on the elicitation of students' ideas. We saw this effect most prominently in the posttest, where students continued to express parent-to-offspring transformational, anthropomorphic, teleological, external agency and Lamarckian conceptions in response to tasks in which within-species variation is not represented (i.e., cheetah, sparrow, desert plants tasks). In the case studies, we were able to observe a context pattern in the elicitation of both normative and alternative conceptions. From pre to posttest, the four case study students revealed a shift from alternative to normative conception in tasks where an initial state of the varied population of organisms were shown to them. In contexts where they were not given this information, however, all four participants continued to evoke alternative conceptions.

How Do Young Children's Alternative Conceptions Change or Persist After Their Participation in an Instructional Course That Scaffolds the Mechanism of Natural Selection Through Cases of Microevolution?

This study demonstrates the potential efficacy of a curriculum designed to scaffold fundamental concepts of natural selection in elementary school education with the objective of guiding students to a better understanding of natural selection and a robust grasp of its underlying principles. With the exception of cyclical and Lamarckian conceptions, the analysis of the two cohorts demonstrated a decline in the frequency of expressed alternative conceptions approximately by a factor of two. In the four case studies, which were representative of the two cohorts as a whole, we observed how despite different biases toward particular conceptions, all four demonstrated a reduction in alternative conceptions in tandem with an increase in their scientific conceptions after participating in the instructional course. These findings provide an existence proof that through participation in an instructional course that scaffolds the mechanism of natural selection through cases of microevolution, young children's reliance upon alternative conceptions in their explanations about evolutionary phenomena could be dramatically reduced.

Questions Emerging From Study Limitations

How representative are the tendencies documented in this study? This study documented patterns of evolutionary explanations in a dataset and sample of 120 interviews derived from 47 participants. Although the aim of the targeted sample was to reflect the complex environment of a public school setting (i.e., inner city public school, predominantly ethnic minority, predominantly low student economic status (SES) student populations), the self-selection of participants, whose parents applied for their children to be a part of the summer program, may have biased our sample and responses. Currently the research team of the larger project is analyzing the results of student interviews from its enactment of the curriculum at another site in public classrooms (predominantly ethnic minority, predominantly low SES) during the school year. The comparison of pre- and posttest results between the summer program cohort and school year cohort will determine to a greater degree the external validity of these results.

What specific features in the context of individual assessment tasks account for the patterns of response to those tasks? Consistently throughout the study, the most dramatic reductions of alternative conceptions from pre- to posttest were found in the *Brassica rapa*/cricket, guppy and butterfly tasks. Throughout the study, the inclusion or exclusion of a single salient feature arose to distinguish this set of tasks from those that showed the weakest reductions, i.e., representation of variation, an idea considered fundamental to an understanding of natural selection (Mayr, 1999). It has also been found that drawing students' attention to within-kind variation is highly effective in replacing transformational conceptions with variational ideas (Shtulman & Calabi, 2008). It was thus considered an important task feature in explaining pre- to posttest gains that were observed across tasks in this study.

One limitation of this study, however, was the set of multiple features within each assessment task, which precludes the identification of specific feature effects. For example, multiple aspects of the guppy task (i.e., prediction and explanation structure, microevolutionary phenomena, variation represented in the stem of the task, dichotomous traits represented, use of visual icons to represent prediction) may have facilitated the improvement that we observed from pre- to posttest. This study, however, was not designed to isolate and measure the impact of those individual features. Similarly throughout the study the lowest reductions in alternative conceptions from pre- to posttest were found in the cheetah and House Sparrow tasks. The features that differentiated these tasks from those that elicited more normative responses (i.e., explanation "looking back" structure, non-microevolutionary phenomena, variation not foregrounded in the stem of the task, continuous traits represented, no use of visual icons to represent explanation) were, again, not assessed for individual impact. A future study that controls for each task feature may identify more conclusively which specific aspects of the task or combination thereof elicited the patterns observed in this study.

What is the relationship between normative and alternative conceptions in students' explanations? In the four case studies, we observed a pattern between the students' alternative and normative ideas. From pre- to posttest a decline in the students' evocation of alternative conceptions was coupled with an increase in their expression of normative ideas. Although the case studies gave us descriptive accounts of this dynamic relationship in the case of four individuals, their general implications were necessarily limited. Those implications will be further explored in future analyses. One of these, currently conducted by the research team of the larger project, will examine the normative conceptions of all project participants whose alternative conceptions were the focus of this study. A third analysis, which I will conduct with the research team from the larger project, will then combine analyses from the two studies to form a broad picture of the pre- and posttest patterns between students' alternative and normative conceptions. It will also consider the predictive potential of specific alternative conceptions as regards students' improvement from pre- to posttest.

What is the relationship between a student's idea and his or her ability to express it? Throughout the analyses in this study the author was confronted with ambiguities of interpretation arising from the ways the students expressed themselves. In numerous examples the attribution of human characteristics to animals and plants (e.g., "The seeds would evolve and stand up to the caterpillars by growing hairs") could be interpreted either as a non-normative idea or as a means of expressing complex thoughts—in effect, an unintentional metaphor. For the speaker a metaphor may be a useful gloss, an abbreviation of concepts too dense or ungainly to spell out in other terms. For the hearer, a metaphor may sound like misconception—particularly when expressed in a child's language. The use of teleological language provides the same conflicting interpretations of students' understanding. It has been noted that even "Darwin's language may seem teleological, but his thinking is another matter" (Ghiselin, 1994).

The dramatic reduction of anthropomorphic and teleological responses from pre- to posttest recorded in this study lends itself to competing interpretations. It may indicate the effectiveness of the instructional course in replacing naïve ideas with scientifically sound principles—or it may suggest that the course gave to students a way of *speaking* about evolution that did not require the gloss of an anthropomorphic or teleological metaphor.

Study Implications

What are the implications of this research in the science classroom? First, evolution instructors should be aware that young children enter the classroom with cognitive biases that inform the way they interpret and explain evolutionary phenomena, and that the conceptions that arise from these biases are closely related to those of secondary and university students. Second, if students are understood to be reasoning from a varied set of alternative conceptions stemming from their cognitive biases, instruction may be directed toward building off aspects of those cognitive biases that are amenable to building a foundation for normative understanding. Third, the normative and alternative conceptions that students express are sensitive to the context of the evolutionary phenomenon. Thus, in assessing student understanding about evolution, educators should take into consideration the effect of context on student responses. Finally, this study establishes that through effective scaffolding, students at this young age can diminish their reliance upon alternative conceptions as they come to understand the mechanisms of natural selection.

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Appendix

YEAR ONE STRUCTURED INTERVIEW ASSESSMENT INSTRUMENT

TASK ONE: OTTER AND KELP

Materials

- Two images

Introduction

"I have a couple pictures of sea otters I want to show you. What do you see here?"
[Give child time to look at the pictures and answer.]

OTTER QUESTIONS

1) Reasoning for why it lives there

"Why do you think otters live there?"
[Point to picture as you say this and wait for response.]

"What are other reasons why otters they live there?"

"What are other reasons why you think they live there?"
[Probe for three reasons.]

2) Reasoning about where else it could or couldn't live

"Do you think the otters could live in other places too?"

If no:

"Why not? Why couldn't live anywhere else?"

"What's another reason you think they could just live there?"

If yes:

"Where else do you think they could live?"

"Why do you think they could live there?"

"Is there a place they couldn't live?"

"Why couldn't they live there?"

"What might be another reason they couldn't live there?"

KELP QUESTIONS

1) Reasoning about why it lives there

"What about the kelp, this stuff. Kelp is a kind of plant that lives in the sea.
Why do you think it lives there?"

2) Reasoning about where else it could or couldn't live

"Are there other places kelp could live?"

If no:

"Why not? Why couldn't kelp live anywhere else?"

"What's another reason you think it could just live there?"

If yes:

"Where else do you think kelp could live?"

"Why do you think it could live there?"

"Is there a place kelp couldn't live?"

"Why couldn't it live there?"

"What might be another reason it couldn't live there?"

TASK TWO: *BRASSICA RAPA* OR MUTE WING CRICKET ITEM

(Depending on class assignment)

2A. HAIRY *BRASSICA RAPA* PLANTS

(for kids in botany class *only*)

Materials

Part I:

- Image of hairless *Brassica*
- Image of hairy *Brassica*
- Field with 16 hairless *Brassica* and 4 hairy *Brassica*
- Caterpillar icons
- Loose set of 16 hairy and 16 non-hairy.
- Template of field

Introduction

"A scientist went to a field to study a kind of plant called a *Brassica*."
[Show image of field with 16 hairless Brassica *and 4 hairy* Brassica.*]*

"[S]he noticed something really interesting about the *Brassicas* in these fields. Almost all of them had very smooth stems: they looked like this. *[Point to some smooth-stemmed* Brassica.*]* But a small number of them had hairy stems: They looked like this." *[Point to hairy-stemmed* Brassica.*]*

1) Environmental Press: Introduction of the Caterpillars

"One day the scientist noticed some caterpillars come into the field!"
[Add two sets *of caterpillars to the image. Place between, not on, plants.]*

"The caterpillars found the *Brassicas* and began to eat them!"

"So which Brassicas do you think the caterpillars will be more likely to eat?"
[Wait for response]

If S thinks they'll be more likely to eat the smooth ones:

"Yes."

If S thinks they'll be more likely to eat the hairy one

"Actually the ones with the smooth stem! The hairs on these *Brassicas [point to the a* couple *hairy stemmed plants]* protect the plant from the caterpillars, so they are less likely to be eaten."

2) Prediction of Generation Two with Icons

a) Request for prediction

"The scientist had to leave the field with the *Brassica* plants and the caterpillars. A year later, [s]he went back to see what the *Brassica* plants looked like. The scientist knew the *same* plants wouldn't be living anymore, because *Brassica* plants don't live that long. You are one generation after your parents. The seeds from a plant grow up into the next generation of plants. Since [s]he went back a year later, [s]he knew [s]he'd see the next generation of *Brassica* plants, the children of the *Brassicas* [s]he saw when [s]he first got there."

"Use whatever you need of this stuff to show what you think the *Brassica* plants looked one generation after the caterpillars got there." *[Provide set of 16 hairy and 16 non-hairy* Brassicas*; the field template with two caterpillar icons pasted on.]*

b) Explaining prediction, using icons

"What do you think the *Brassicas* looked like one generation later, after the caterpillars got there? Use what you did here to explain to me what you think will happen."

If the child does not quantify icons

"I want to make sure I understand your idea. What do you have here?"
[If S wants to adjust numbers as [s]he is in the process of quantifying, allow. The issue here is child's intention, not necessarily an accurate counting thereof. For example, if the child intended to put out 13 hairy plants and 3 non-hairy, that is what is important, not the fact that they actually put out 12 and 4]

If just one template

"Will they all look like this?"

3) Explanation of Mechanism of the change

"So when the scientist first came, the *Brassicas* looked like that *[point to original state]*. And you think that the *Brassicas* in the next generation will look like that *[point to S's arrangement of icons]*. How will that happen?"

2B. MUTE CRICKETS

(for kids in Animal Behavior class *only*)

Materials

- Cricket with ridges
- Cricket with no ridges
- Image of fly placing eggs into cricket
- Image of island with 16 crickets with ridges on wings (capable of chirping) and 4 crickets with minimal ridges (mute)
- Template of island with flies
- Set of 16 cricket with ridge and 16 without

Introduction

"Have you ever heard crickets chirp? Did you know that male crickets chirp by rubbing their wings together?"

"Let me show you a picture. See, the wings look like this *[show picture, pointing out ridge that allows for chirping]*. They chirp by rubbing these together. This is how crickets chirp!"

"A scientist went to the island where this kind of cricket lived. [S]he noticed something really interesting! Some of the male crickets don't have this ridge on their wings, so they couldn't chirp! Take a look at this cricket wing! This cricket can't chirp!"

"These are pictures of the males crickets [s]he saw when [s]he first came to the island. [S]he noticed that most of the crickets had chirper wings and only a few of them had wings that couldn't chirp." *[Show image with 16 chirpers and 4 nonchirpers.]*

1) Environmental Press

"Then a new kind of fly arrived on the island, a kind of fly that laid its eggs in the crickets' bodies! See, here's a picture of the fly putting its eggs into the cricket *[Show image]*. The eggs growing up in the cricket's body kills the cricket."

"How do you think the flies find the crickets to lay their eggs in?"
[Wait for the kids' ideas.]

If S thinks they'll listen for the chirp:

"Yes."

If S thinks otherwise:

"Actually they listen for their chirps! That's the way they find crickets to lay their eggs in. The flies find crickets to lay their eggs in, by listening for their chirping. The crickets that chirp are easy for the flies to find."

2) Prediction for Generation 2

"[S]he was curious about what the crickets one generation later would look like, the children of the crickets that were there when the flies got there. So [s]he stayed and watched."

a) Request for prediction using icons

"Think about what the crickets looked like one generation later, one generation after the flies got there. Here's an island *[place blank island cut out in front of child, move first picture up]*, and here are some crickets. Use whatever of this stuff you need to show what you think the crickets looked like one generation later after the flies got there."

b) Explaining prediction, using icons

"So what do you think the crickets will look like one generation after the flies get there? Use what you did here *[their arrangement of the icons]* to explain what you think."

If S does not quantify icons:

"I want to make sure I understand your idea. What do you have here?"

If only one template:

"Will they all look like this?"

3) Explanation of Mechanism of the change

"So when the scientist first came, the male crickets looked like that *[point to image with island 16 crickets with ridges and 4 without pasted on]*. And you think that the ones in the next generation will look like that." *[Point to S's arrangement of icons.]*

"How will that happen?"

TASK THREE: MOTHS

Materials

- Light colored tree trunk with 10 light colored moths and 3 dark colored moths
- Dark colored tree trunk (empty template)
- Set of 2 birds in flight (that eat moths)
- Set of 13 light colored and 13 dark colored moths
- Image of dark trunk with 3 light colored and 10 dark colored moths

Introduction

"Some other scientists have been studying a kind of moth! Some of the moths are dark colored *[show dark colored moth icon]* and some of the moths are light colored." *[Show light colored moth icon.]*

"During the day, they rest on the trunks of trees. Can you find a dark colored moth on the trunk?" *[Wait until child finds one.]*

"Can you find a light colored moth on the trunk?" *[They are well camouflaged. Wait until the child finds one.]*

"Good looking!"

"Scientists many years ago noticed that most of this kind of moth looked like this *[point to light colored moths on tree trunk image with light trunk]*, but some of them looked like this *[point to the 3 dark moths on same image]*. Birds hunt for the moths during the day and eat the ones they find! *[Place a bird in flight near the tree trunk.]*

1) Introduction of environmental press

"Lots of factories came to the place where the moths lived. And the air got really dirty. The air got so dirty that even the tree trunks got dirty too. They are got dirtier and dirtier, so dirty they turned black! Like this." *[Show dark trunk template.]*

2) Request for prediction using icons 20 generations later

"I want you to think about what happened to the moths that lived there. Not these moths *[on original light colored tree trunk]*. But the moths 20 generations later, when the tree trunks were so dirty they looked like this!" *[Point to dark trunk.]*

"20 generations is a long time! You are one generation after your parents. You are two generations after your grandparents. This is 20 generations later! 20 generations later is lots of greats. The great great great ... lots of greats ... grandchildren of these moths." *[Point to original state.]*

"Use these things to show what you think the moths looked 20 generations later when the tree trunk had gotten really black!"

If S says the moths get dirty too, explain:

"The trees live much much longer than the moths. The moths in their short life time don't get dirty. Their lives are too short to get dirty like that."

3) Explanation of + 20 generation prediction, using icons

"So what do you think the moths will look like 20 generations later after the trunks get really black? Explain what you think will happen, using this stuff."

If the child does not quantify icons:

"I want to make sure I understand your idea. What do you have here?" *[If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]*

[Interviewer may need to clarify what child is pointing to for coder. If child says "mostly this," you might say "mostly the dark ones?" Use whatever term child is using to name the category.]

If just one template:

"Will they all look like this?"

4) Explanation of mechanism of the + 20 change

"How will that happen?"

5) Empirical scaffolding re moths 20 generations

a) Interpretation of the phenomenology of what actually happened

"Let me show you what the scientist saw 20 generations later!"

"How is that different than the way they were before, 20 generations before?"

b) Explanation of the mechanism

"How do you think that happened?"

[Go directly to guppy task if student gives a natural selection explanation, including:

- Changing survival value of moth coloration
- How change in survival value of this inherited trait results in increasing frequency of moths with dark coloration from one generation to the next

Note: We would also like S to also mention inheritance, but absence of this alone does not require going through dynamic assessment questions]

4) Dynamic Scaffolding

a) L4 Scaffolding: Survival advantage of trait

"How do you think being the same color of the tree could help the moth?"
[Wait until they think this through before continuing.]

b) LP5 scaffolding: Survival and reproductive advantage of trait

"In every generation, not all moths survive long enough to have babies."

"Once the trees get really dirty, which moths do you think will have the best chance to survive long enough to have babies? The white moths or the dark moths?" *[Wait for response.]*

"Why do you think those will be the ones that survive?" *[Wait until they think this through before continuing.]*

c) Inheritance + population scaffolding

"Their color is something that moths get mostly from their parents. So light moths usually have light babies. And dark moths usually have dark babies. Moths inherit their color from their parents."

"Let's say there are five light moths and five dark moths in one group living together. Which of those moths do you think will be most likely to live long enough to pass on their color to the next generation? The light ones or the dark ones?" *[Wait for response.]*

"So what difference would that make for the number of light colored moths and dark colored moths in the next generation?" *[Wait for response.]*

5) Return to the full puzzle

"So I'd like you to think again about that first question. How did the moths color change? How did that happen?"

6) Can child revoice a normative explanation

"Another kid told me that after the tree trunks got black, the moths that were dark colored had a better chance of not getting eaten by the birds, because the birds were less likely to find them. So the dark moths were more likely to live long enough to have young. And since moths inherit their color, the young born from the dark moths grew up to be dark too!"

"And this other kid told me that after the trunks get black, in each generation, the moths that were dark had a better chance of surviving and having babies that survived. So in each next generation there were more dark ones and fewer light ones. What do you think [s]he meant?"

7) Evaluation of explanation

"Do you think [s]he was right or wrong? Why?"

TASK FOUR: GUPPIES

Materials

- Image of river with 12 colorful guppies and 4 camouflaged glued on (original state)
- 2 predator fish (to add to original state)
- 16 colorful guppies and 16 camouflaged guppies (for child to use to make predictions)
- Image of river with just 3 predators attached and no guppies (template to use in predictions)
- Image of pool with 10 camouflaged guppies, 6 colorful guppies and 3 predators. (Empirical feedback: what they fish looked like in Generation Two)

Introduction

"There's another scientist who studies fish and where they live. This scientist went to study a kind of fish called a guppy. [S]he went to a river where the guppies lived. There were waterfalls on the river. And different pools between the water falls where different groups of the guppies lived."

"Let me show you a picture of one of the pools she studied and the guppies that lived there." *[Show image.]*

1) Variation: Do they represent it? View as important?

"What do you notice about the guppies in this pool?"

If they don't attend to the difference in coloration:

"Are some more colorful than the others?"

2) Introduction of environmental press

"In this pool, the scientist didn't see any kind of fish that ate guppies. But [s]he knew that some pools in the river had a kind of fish that ate the guppies."

"One day, [s]he noticed some of the predator fish, fish that eat the guppies, come over the waterfall." *[Position predator fish on the template, with fish at both sides of the pool.]*

"[S]he wondered what would happen to the guppies. So she watched very carefully. [S]he was very curious about what the next generation of guppies would like look, the children of the guppies that were there when the predator fish first got there."

3) Request Prediction of guppies in Generation 2

"I want you to think about what the guppies looked like one generation after the predator fish, the fish that ate the guppies, got there. Think about what the children of these guppies *[point to image of pool with 12 colorful guppies and 4 camouflaged]* looked like."

[Move first picture up. Place blank template and sets of colorful and camouflaged guppies in front of child.]

"Use any of this stuff you need to show what you think the guppies looked like in this pool one generation later."

[While child is working, remove predator fish from first picture so that it is back to its original state.]

a) Explaining prediction, using icons

"How are these guppies *[point to S's prediction]* different from the ones in the pool before the predators got there?" *[Point to original state.]*

If the child does not quantify icons:

I want to make sure I understand your idea. What do you have here? *[If S* wants *to adjust numbers as [s]he is in the process of quantifying, allow.]*

[Interviewer may need to clarify what child is pointing to for coder. If child says "mostly this," you might say "mostly the colorful ones?" Use whatever term child is using to name the category.]

If just one template:

"Will they all look like this?"

[The issue here is child's intention, not necessarily an accurate counting thereof. For example, if the child intended to put out 13 chirpers and 3 non-chirpers, that what is important, not the fact that they actually put out 12 and 4.]

4) Explanation of Mechanism of the + 1 generation change

"How will that happen?"

5) Interpretation of the phenomenology of what happened and why G1 /G 2

a) What happened: Empirical feedback

"Let me show you what the scientist actually saw!" *[Cover child's prediction with image of pool with 10 camouflaged guppies 6 colorful guppies and 3 camouflaged guppies]*

"What happened? How are these guppies different from the ones in the pool before the predators got there?"

b) Explanation of the mechanism

"How do you think that happened?"

6) Request Prediction of guppies in Generation 5

"The scientist stayed by the river, because [s]he was curious what the guppies would look like after another 3 generations after this one." *[Point to image of pool with 10 camouflaged guppies 6 colorful guppies and 3 predators.]*

"The predator fish were still there. Think about what the guppies looked like three generations after this. The grandchildren of these guppies." *[Move generation 1 and generation 2 pictures up, place cleared template and guppy cutouts in front of child.]*

"Use any of this stuff you need to show what you think the guppies looked like in this pool three generations later."

7) Explain prediction

"How are these guppies different from the ones in the pool three generations earlier?"

"What do you have here?" *[Encourage S to quantify types, so we have this on video. If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]*

If just one template:

"Will they all look like this?"

8) Explanation of Mechanism to account for Generation 5

"How will that happen?"

TASK FIVE: CHEETAHS

Materials

- 2 pictures of cheetahs in their environment

1) Explanation of the change problem

"Let me show you some photos of cheetahs!"

"Most cheetahs today can run really fast. Some can run as fast as 65 miles an hour! As fast as a car! But scientists know that the cheetahs that lived a long time ago, their ancestors couldn't run nearly this fast. They couldn't run that fast *even if they really tried*. They could only run 20 miles an hour, as fast as a bicycle."

"How come most cheetahs today are able to run so much faster than their ancestors, the ones that lived a long ago? How you do think scientists would explain that?"

[Stop here if full explanation, including:

- *Survival value of a cheetah being faster*
- *How survival value of this trait results in increase of fast cheetahs from one generation to the next.]*

2) Dynamic Scaffolding of Explanation

a) L4 Scaffolding: Survival advantage of trait

"How do you think being fast could help the cheetah?"
[Wait until they think this through before continuing.]

b) LP5 Scaffolding: Survival and reproductive advantage of trait

"In every generation, not all cheetahs survive long enough to have babies. Which ones do you think will survive and have babies? The slower ones or the faster ones?"

"Why do you think those will be the ones that survive?" *[Wait until they think this through before continuing.]*

c) LP6 Scaffolding: Survival and reproductive advantage of trait & Shift in distribution of traits in a population

"Speed is something that cheetahs get mostly from their parents. So the faster cheetahs usually have babies can run fast when they grow up. And the slower cheetahs usually have babies that are slow when they grow up. Cheetahs inherit their speed from their parents."

"Let's say there are 10 cheetahs living in a group. Which of those cheetahs do you think will be most likely to live long enough to pass on their speed to the next generation? The faster ones or the slower ones?"

"So what difference would that make for the number of baby cheetahs in the group that inherit a faster speed and the number of baby cheetahs that inherit a slower speed?"

5) Return to the full puzzle

"How come most cheetahs today are so much faster than their ancestors, the ones that lived a long ago?

[Stop here if full explanation, including:

- *Survival value of a cheetah being faster*
- *How survival value of this trait results in increase of fast cheetahs from one generation to the next.]*

6) Revoicing and explanation of LP7: Over many generations, inherited traits that help organisms' chance to survive and reproduce where they live will become more common

"Another kid/person told me that the cheetahs that were especially fast had a better chance of getting enough food. *So* the faster cheetahs were the ones that survived long enough to have young. And the faster cheetahs were the ones who were able to get enough food to feed to their young, so their young had a better chance of surviving too. And since cheetahs mostly inherit speed, the young born from the fast cheetahs grew up to be fast too! In each generation, the ones that were fast had a better chance of surviving and having babies that survived. So in each next generation there were more fast ones and fewer slow ones. So cheetahs have gotten faster and faster. They have really changed. They are now much faster. That's why cheetahs today are so much faster than their ancestors."

a.) Can S revoice?

"What do you think [s]he meant?"

b) Evaluation of explanation

"Do you think [s]he was right or wrong? Why?"

YEAR TWO STRUCTURED INTERVIEW ASSESSMENT INSTRUMENT

TASK ONE: RAINFOREST/DESERT PLANTS

Materials:

- Photo of Rainforest
- Photo of Desert

Introduction

"Take a look at these plants!" *[Place side by side on the table.]*

"These plants *[point to rainforest image]* live in the rainforest. These plants *[point to desert image]* live in the desert."

1) Possible to switch environments?

a) From rainforest to desert?

"Do you think these plants – that live in the rainforest – could survive in the desert too?"

If no:

"Why not?"

"Any other reasons?"

If yes:

"Are there any places in the world that these plants *[gesturing to rainforest plants]* couldn't live?"

If S names or identifies a place they couldn't live:

"Why couldn't these plants live there?"

"Is there any other reason they couldn't live there?"

b) From desert to rainforest?

What about these plants that live in the desert *[point to desert plant photo]*? Do you think these plants could survive in the rainforest too?

If no:

Why not?

Any other reasons?

If yes:

Are there <u>any</u> places in the world that these plants [gesturing to desert plants] couldn't live?

If S names identifies a place they couldn't live:

Why couldn't these plants live there?

Is there any other reason they couldn't live there?

2) Explanation of fit

"I've got another question for you about these desert plants. How come they can survive here in the desert where there is so little water?"

TASK TWO: *BRASSICA RAPA* OR MUTE WING CRICKET ITEM

(Depending on class assignment)

2A. *BRASSICA RAPA*

(For Botany kids only)

Materials:

- Original field with: Field before the caterpillars got there
- Caterpillar templates (to add to Field 1)
- One blank field templates
- One set of *Brassica rapa* icons, each including 14 hairy BR and 14 hairless BR [Mixed up set]

Functions:

- Differentiate LP 5/6 version 1; LP 4/5/6/7 on new version
- Testing that taught in curriculum. Minimal transfer.
- No support of the form of either empirical feedback or dynamic assessment

1) Framing of the problem

"Here's a field of a type of plant called *Brassica rapa*. Check out the hairs. Some of these *Brassica rapa* have lots of hairs *[point to hairy plant]*. And some don't have any hairs *[point to hairy plant]*. Can you find one that has hairs? Can you find one that doesn't have hairs?"

"One day, caterpillars came to this field [Add two sets of caterpillars to the image]. The caterpillars found the *Brassicas* and began to eat them! Caterpillars like to eat this kind of plant! But they don't seem to like the hairy ones. They mostly eat the smooth-stem ones."

2) Generation Two (with icons)

a) Formation of prediction

"So think about what the *Brassica rapa* in the field with the caterpillars would look like one year later. Even one year later, they won't be the same plants because they die off in the fall after dropping their seeds."

"In the wild fields, *Brassica rapa* drop their seeds each fall and new plants grow up from those seeds in the spring. So each year there is a new generation of the *Brassica rapa* that grow up and have seeds of their own."

"What do you think the *Brassica rapa* in this field will like look one year after the caterpillars get there, the next generation of *Brassica rapa*."

"Use any of this stuff you need to show your prediction."

Ask after S has completed prediction with icon:

"So what do you think the plants will look like in the field, one year after the caterpillars get there, one generation later?"

If the child does not quantify icons:

"I want to make sure I understand your idea."

"What do you have here?" *[If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]*

[The issue here is child's intention, not necessarily an accurate counting thereof. For example, if the child intended to put out 13 hairy plants and 3 non-hairy, that what is important, not the fact they actually put out 12 and 4]

b) Generation One > Generation Two: Explanation of mechanism of the change

"So just after the caterpillars got there, the plants looked like this *[point to generation 1]*. And you predict that one generation later, they'll look like this *[point to generation 2]*."

"So how will that happen?"

[If child is lower than LP4, omit Generation 5.]

3) Generation 5 (verbal)

"Now think about what the *Brassica rapa* will look like in the field 5 years after the caterpillars get there. So that would be 5 generations later: That's five cycles of plants growing up and having seeds and those seeds making new plants."

a) Prediction

"So what's your prediction for what the plants will look like five years after the caterpillars got there, five generations later?"

"Do you think they'll be the same as one generation after the caterpillars get there [point to Generation 2 prediction] or do you think they'll be different?"

If S says different:

"What do you think the BR will look like 5 years after the caterpillars get there?" *[If the child uses the materials to answer the question, allow it.]*

b) Explanation

"So how do you think that will happen?"

2B. CRICKETS

(for Animal Behavior kids *only*)

Materials

- Cricket with ridges
- Cricket with no ridges
- Image of fly placing eggs into cricket
- Image of island with 16 crickets with ridges on wings (capable of chirping) and 4 crickets with minimal ridges (mute)
- Template of island with flies
- Set of 16 cricket with ridge and 16 without

Introduction

"Have you ever heard crickets chirp? Did you know that male crickets chirp by rubbing their wings together?"

"Let me show you a picture. See, the wings look like this *[show picture, pointing out ridge that allows for chirping]*. They chirp by rubbing these together. This is how crickets chirp!"

[Do gender match.]

"A scientist went to the island where this kind of cricket lived. [S]he noticed something really interesting! Some of the male crickets don't have this ridge on their wings, so they couldn't chirp! Take a look at this cricket wing! This cricket can't chirp!"

"These are pictures of the males crickets [s]he saw when [s]he first came to the island. [S]he noticed that most of the crickets had chirper wings and only a few of them had wings that couldn't chirp." *[Show image with 16 chirpers and 4 nonchirpers.]*

3) Environmental press:

"Then, a new kind of fly arrived on the island, a kind of fly that laid its eggs in the crickets' bodies! See, here's a picture of the fly putting its eggs into the cricket *[show image]*. The eggs growing up in the cricket's body kills the cricket."

"How do you think the flies find the crickets to lay their eggs in?" *[Wait for the kids' ideas.]*

If S thinks they'll listen for the chirp:

"Yes."

If S thinks otherwise:

"Actually they listen for their chirps! That's the way they find crickets to lay their eggs in. The flies find crickets to lay their eggs in by listening for their chirping. The crickets that chirp are easy for the flies to find."

2) Generation two (with icons)

a) Formation of prediction

"So think about what the crickets on the island with the flies would look like one year later. Even one year later, they won't be the same crickets because they don't live that long. In the wild, crickets mate and have babies that grow up to become adult crickets. So each year there is a new generation of the crickets that grow up and have babies of their own."

"What do you think the crickets on this island will look like one year after the flies got there – the next generation of crickets?"

"Use any of this stuff you need to show your prediction."

Ask after S has completed prediction, with icon:

b) Child's description of their prediction

"So what do you think the crickets on the island will look like one year after the flies got there, one generation later?"

If the child does not quantify icons:

"I want to make sure I understand your idea. What do you have here?" *[If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]*

[The issue here is child's intention, not necessarily an accurate counting thereof. For example, if the child intended to put out 13 chirpers and 3 non-chirpers, that what is important, not the fact they actually put out 12 and 4]

c) Generation One > Generation Two: Explanation of mechanism of the change

"So just after the flies got there, the crickets looked like this *[point to generation 1].* And you predict that one generation later, they'll look like this *[point to generation 2].*"

"So how will that happen?"

If child is lower than LP4, omit Generation 5

3) Generation 5 (verbal)

"Now think about what the crickets on the island will look like on the island five years after the flies got there. So that would be five generations later. That's five cycles of cricket growing up and having babies that grow up into adult crickets."

a) Prediction

"So what's your prediction for what the plants will look like five years after the flies got to the island, five generations later?"

"Do you think they'll be the same as one generation after the flies got there *[point to Generation 2 prediction]* or do you think they'll be different?"

If S says different:

"What do you think the crickets on the island will look like five years after the flies got there? *[If the child uses the materials to answer, allow it.]*

b) Explanation

"So how do you think that will happen?"

TASK THREE: GUPPIES

Materials:

- Image of river with 12 colorful guppies and 4 camouflaged glued on (original state; Mixed sets)
- 2 predator fish (to add to original state)
- 16 colorful guppies and 16 camouflaged guppies (for child to use to make predictions)
- Image of river with just 3 predators attached without guppies (template to use in predictions)
- Image of pool with 10 camouflaged guppies, 6 colorful guppies and 3 predators. (template with empirical feedback to show what the fish looked like in Generation Two)

Introduction

"There's a scientist who went to study a kind of fish called a guppy. [S]he went to a river where the guppies lived. There were waterfalls on the river, and different pools between the water falls where different groups of the guppies lived. Let me show you a picture of one of the pools [s]he studied and the guppies that lived there." *[Show image.]*

"What do you notice about the guppies in this pool?"

If they don't attend to the difference in coloration:

"Are some more colorful than the others?"

"One day, she noticed some predator fish, fish that eat guppies, come over the waterfall! *[Position predator fish at the top of the template, just above the pool.]* She wondered what would happen to the guppies. So she watched very carefully. She was very curious about what the next generation of guppies would like look. So she went back a year later."

"She knew she wouldn't see the same guppies, because no guppies could live that long. She knew the guppies that would be there when she got back would be the children of the ones she had first seen, but now all grown up. It would be the next generation of guppies after the predator fish first got there."

1) Request Prediction of guppies in Generation 2

"This is what the guppies looked like when the predator fish first got there *[point to Generation 1 template]*."

"Think about what the guppies will look like one generation after the predator fish, the fish that eat the guppies, got there."

"Use any of this stuff you need to show what you think the guppies will look like in this pool one generation later."

Ask after S has completed prediction, with icon:.

a) Explaining prediction, using icons

"How are these guppies *[point to S's prediction]* different from the ones that lived in the pool before the predators got there?" *[Point to original state.]*

If the child does not quantify icons,

"I want to make sure I understand your idea. What do you have here?"
[If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]

2) Explanation of mechanism of the + 1 generation change

"How will that happen?"

3) Interpretation of the phenomenology of what happened and why: Generation 1 / Generation 2

a) What happened: Empirical feedback

"Let me show you what the scientist actually saw!" *[Place image of pool with 10 camouflaged guppies 6 colorful guppies and 3 ABOVE the image of pool the way scientist first saw them.]*

"What happened? How are these guppies different from the ones in the pool before the predators got there?"

b) Explanation of the mechanism

"How do you think that happened?"

4) Request Prediction of guppies in Generation 5

"The scientist stayed by the river, because [s]he was curious about what the guppies would look like after another 3 generations after this one [Generation 2] *[Image of pool with 10 camouflaged guppies 6 colorful guppies and 3 predators].* The predator fish were still there. What do you think the guppies looked like three generations after these guppies? The grown-up grandchildren of these guppies?"

"Use any of this stuff you need to show what you think the guppies looked like in this pool three generations later."

5) Explain prediction

"How are these guppies different from the ones in the pool three generations earlier?"

TASK FOUR: BUTTERFLIES

Materials

- Banded peacock butterflies: plain winged, striped
- Original Environment template with 5 plain winged and 5 striped
- Birds to add to the template
- Template labeled "50 generations later I predict the butterflies will look like this

1) Explain prediction

"Here are some pictures of a kind of butterfly called a Banded Peacock butterfly. What do you notice about them?" *[Pause.]*

"Their wings are really different! Some of them have striped wings. *[Point to butterfly with striped wings].* And some don't have stripes; their wings are just plain black."

Recently a new kind of bird came to the place where these butterflies live. *[Put two birds onto template with the butterflies]* Scientists have noticed that these birds attack the butterflies and hurt their wings. The birds mostly attack the butterflies with striped wings. They don't seem to attack the plain-winged ones very much.

2) Request Prediction of butterflies in Generation 50

"Think about what the butterflies will look like 50 years after the birds got there."

"Of course, they won't be the same butterflies pictured here because butterflies don't live nearly that long. Fifty years later it will be butterflies that are descended from these butterflies, 50 generations later."

"Take a look at these pictures. Does one of these pictures show what you think the butterflies will look like 50 years after the birds that attack them get there … or not?"

If the child begins answering, it's okay not to read through the next section

"This picture shows them just the same, no change, 50 years later, still about 2 plain ones for every 8 striped ones."

"This picture shows them with them with about half and half."

"This picture shows them with more plain ones than striped ones."

"And this picture shows just plain ones."

"Does one of these pictures show what you think the butterflies will look like 50 years after the birds that attack the striped ones gets there?"

3) Explanation of mechanism to account for Generation 50

"How do you think that will happen?" *[Encourage S to quantify types, so we have this on video. If S wants to adjust numbers as [s]he is in the process of quantifying, allow.]*

[Stop if full explanation is given]

Dynamic Assessment to Explain What Happened

STEP 1: Suggest considering implication of survival value of individual's traits

[Offer if student has not reflected understanding of survival value/risk of trait]

"Remember, if a butterfly has striped wings, it is more likely to get attacked and have its wings damaged and even get killed. What difference does that make for the butterflies that live there 50 generations after the birds get there?"

[Stop if full explanation is given]

STEP 2: Suggest considering implications of differential survival value of different inherited traits leading to increase to next generation of advantaged trait

"Wing coloring is something the butterflies inherit from their parents."

“Just like really tall parents usually have tall kids, the butterflies usually have wing coloring like their parents.”

“And, butterflies with plain wings have a better chance of surviving long enough to have offspring—have babies—than than the butterflies with striped wings, so there are likely to be more plain-winged ones in the next generation.”

“What difference would that make for the butterflies that live there 50 generations later?”

[Stop if full explanation is given]

STEP 3: Revoicing and evaluation of normative explanation

Use the pictures to help the student track this explanation.

“See what you think of this kid’s idea: This kid said after the birds get there, there will be more plain ones and fewer striped ones in each generation.” [*Point to all for picture options one-by-one, starting with the one with the most striped ones, and going across to the one with no striped ones. (I will call them A, B, C, and D, respectively, in this document.]*

“Because in each generation, the ones with plain wings have a better chance of living long enough to have babies.” [*Point to a plain winged butterfly in A.]*

“And their babies grow up to have plain wings too, because butterflies inherit their wing coloring from their parents.” [*Point to a plain-winged butterfly in A , Then point to a plain-winged on in B.]*

“So the number of plain-winged butterflies that live there will get bigger and bigger.” *[Gesture over the plain-winged ones in A, B, C, and D in turn, you’re trying to draw attention to the fact that the number of plain ones gets bigger.]*

“And the number of striped ones will get smaller and smaller.” *[Gesture over the plain-winged ones in A, B, and C in turn, you’re trying to draw attention to the fact that the number of striped ones gets smaller.]*

“Some day there may not even be any striped ones left.” *[Point to D]*

a) Revoicing

“So what do you think that kid meant?”

b) Evaluation

“Do you think that kid was right or wrong? Why?”

TASK FIVE: HOUSE SPARROWS

Materials

- Three templates with background + sparrows
- Image 1: Background + population of 10 sparrows of medium size (some variation)
- Image 2: A cold environment where sparrows live with population of relatively large sparrows

- Image 3: A warm environment where sparrow live with population of relatively small sparrows

1) Framing the problem

"A long time ago, more than 100 years ago, someone brought a kind of bird called a house sparrow to the United States. Now they live all over the US, in cold places and warm places. This is what these sparrows looked like when they first got here a hundred years ago."

"Take a close look … are they all just the same size or are some of them a little different?"

"This is what the sparrows look like today where it is warm."

"And this is what they look like where it is cold."

"See how the ones that live where it's cold are a little bit bigger?"

"They are not just puffed up. The grown up birds that live where it is cold are actually a little bigger because their bones are a little bigger." *[Point to the picture of the bigger birds in cold places.]*

2) Explanation of the change

"Think about how that happened. How come the sparrows that live where it's cold are bigger than the ones that first got there a long time ago?"

"We know that being bigger helps the birds stay warm. It helps them survive in the cold. But how did the size of the birds change? How did that happen?"

If the child says, they traveled there or after they first came here, the big ones and little ones went to different places, explain:

"But take a look at what the birds looked like when they first got here."

"None of them were as big as the ones that live in the cold today."

"How could you explain how the sparrows living in cold places are bigger today than the ones that first got there many years ago?"

[Stop if full explanation is given]

Dynamic Assessment to Explain What Happened

STEP 1 Suggest considering implication of survival value of individual's traits

"Remember that if a bird is big, it helps it survive in the cold. If it is small, it is more likely to get really cold and die. How could that explain how come the sparrows that live today where it's cold are bigger than any of the sparrows were when they first got there?"

[Stop if full explanation is given]

STEP 2: Suggest considering implications of differential survival value of different inherited traits leading to an increase in the next generation of the advantaged trait

"The bigger sparrows have a better chance of surviving in the cold because they can stay warm."

“And sparrows mostly inherit their body size from their parents.”

“How could that explain how the sparrows living in cold places are much bigger than the sparrows someone first brought here?”

[Stop if full explanation is given]

STEP 3: Revoicing and evaluation of normative explanation

“Let me tell you what another student told me! And you can tell me if you think [s]he was right or wrong.”

“This kid said there are bigger sparrows where it’s cold, because they have a better chance of surviving there.”

“The smaller ones were less likely to survive long enough to pass on their small size to the next generation.”

“In each generation, there are fewer of the small ones that got cold and didn't live long enough to mate and have young.”

“Over many generations, the sparrows that lived in the cold got a little bigger and little bigger.”

a) Revoicing

“So what do you think that kid meant?”

b) Evaluation

“Do think that kid was right or wrong? Why?”

TASK SIX: CHEETAHS

Materials

- 2 pictures of cheetahs in their environment

Introduction

“Let me show you some photos of cheetahs!”

“Most cheetahs today can run really fast. When chasing prey, some can run as fast as 65 miles an hour! That’s as fast as a car!”

“But scientists know that the cheetahs that lived thousands of years ago, their ancestors, couldn't run nearly this fast. They couldn't run that fast *even if they really tried*. They could only run 20 miles an hour, as fast as a bicycle.”

“How come most cheetahs today are able to run so much faster than their ancestors, the ones that lived thousands of years ago?”

“How you do think scientists would explain that?”

TASK SEVEN: DESERT PLANTS

Materials:

- Image of Teddy bear cholla in its environment
- Image of Century plant in its environment

Introduction

"I'm going to show you a couple of plants that live in the desert, where sometimes it doesn't rain for a really long time!"

"Take a look at this plant *[Teddy bear cholla]*! This plant lives in the desert where there is very little water. From far away, it looks soft and fuzzy, but watch out! *[Point to image of full plant.]* It's covered with lots of sharp spines that help the plant. *[Point to close-up of teddy bear plant.]* The spines stop animals from getting the water inside the plant. It fits really well where it lives!"

"Check out this one *[Century plant]*! It lives in the desert too. This plant stores water in its big thick leaves. It can use this water between rains. The shape of the leaf helps the roots get water. The rain runs down the leaves like this *[run hand down inside a leaf]* to the roots. This plant fits really well where it lives in the desert too!"

"Scientists have found that almost all plants fit really well where they live."

"How do you think that happens?"

"How come most plants fit so well where they live?"

Prepared by Kathleen Metz, Principal Investigator of the NSF project: Developing the conceptual underpinnings of evolution in second and third graders