ANNUAL REVIEWS

Annual Review of Developmental Psychology

Play, Curiosity, and Cognition

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Annu. Rev. Dev. Psychol. 2020. 2:317–43

First published as a Review in Advance on October 13, 2020

The *Annual Review of Developmental Psychology* is online at devpsych.annualreviews.org

https://doi.org/10.1146/annurev-devpsych-070120-014806

Keywords

play, learning, exploration, children, cognitive development

Abstract

Few phenomena in childhood are as compelling—and mystifying—as play. We review five proposals about the relationship between play and development. We believe each captures important aspects of play across species; however, we believe none of them accounts for the extraordinary richness of human play or its connection to distinctively human learning. In thinking about play, we are particularly struck by the profligacy with which children set seemingly arbitrary rewards and incur unnecessary costs. We suggest that researchers take the seeming inutility of play seriously and consider why it might be useful to engage in apparently useless behavior. We propose that humans' ability to choose arbitrary costs and rewards allows us to pursue novel goals, discover unexpected information, and invent problems we would not otherwise encounter. Because problems impose constraints on search, these invented problems may help solve a big problem: how to generate new ideas and plans in an otherwise infinite search space.

Contents

1. INTRODUCTION

Play is one of the most enchanting and baffling phenomena in nature. Among the most accessible of all behaviors, it is also among the most difficult to characterize rigorously. We all recognize play when we see it. Nonetheless, play eludes definition to the extent that a species of play (games) has served to illustrate the limits of classic theories of word meaning (Wittgenstein 2001).

However, if play has defied description, it is not due to lack of study (Lillard 2015). Scientists in fields ranging from ethology to robotics have debated the factors that might motivate play and the functions that play might serve. In this article, we review both noncognitive and cognitive accounts of play, focusing especially on recent research linking play, epistemic curiosity, and learning. Reflecting the traditions in which these accounts are best developed, we review research mostly on nonhuman animals in discussing noncognitive accounts and mostly on humans in discussing cognitive accounts, but the accounts apply across species and are not mutually exclusive: Play might emerge for many reasons, serve many ends, and occur in different forms in a single play session.

Ultimately, however, we conclude that none of the current accounts does justice to the richness of distinctively human play—or distinctively human curiosity and cognition. We argue that understanding play in human beings requires taking its apparent uselessness seriously. Indeed, we suggest that among the most salient features of human play is the degree to which we intervene on our own utility functions. That is, in play, humans willingly adopt arbitrary rewards and incur unnecessary costs, leading to systematically different behavior in play than in other forms of intentional, goal-directed behavior. We suggest that this willingness to incur unnecessary costs to achieve idiosyncratic ends allows humans to create a vast array of problems we would not otherwise have. We propose that these invented problems, and the constraints they impose, help solve a big problem: how to generate new ideas and plans in an otherwise infinite search space.

2. NONCOGNITIVE ACCOUNTS OF PLAY

2.1. Play for Pleasure

We begin by discussing noncognitive accounts of play, starting with what is surely the simplest possibility: that play has no function at all. We may play just for the pleasure of it. More precisely, insofar as animals evolved to find behaviors that increase reproductive success rewarding, they may be expected to engage in these behaviors often, even in contexts where they confer no advantage. Thus, if it is rewarding for dolphins to blow bubbles into nets to hunt fish (Ingebrigtsen 1929, Jurasz & Jurasz 1979, Sharpe & Dill 1997), they may also blow bubble rings just for fun (**Figure 1*a***) (Delfour & Aulagnier 1997, McCowan et al. 2000, Pace 2000); if it is positively arousing for chimpanzees to swing, jump, and leap to travel through the forest, they may do so just for the pleasure of it (Mears & Harlow 1975); and if a preference for colorful, soft substances allows primates to detect ripe fruit (e.g., Dominy et al. 2003), they may then enjoy playing with colorful, squishy things in any context (witness the 280 million Google search results associated with the current slime craze).

These are, of course, "just so" stories; here, however, they serve as "just not so" stories, explaining not why an observed behavior fulfills an adaptive end but why it may not—why playful behaviors may simply be generalizations of behaviors that are functional in other contexts. In this sense, play may be an evolutionary spandrel (Gould & Lewontin 1979), persisting only because it is reinforced by reward systems evolved for other purposes. Of course, our difficulty imagining how some behaviors—blowing bubble rings, playing with slime—could be useful does not mean that no such use exists. The anthropologist Robin Dunbar cautioned against the so-called spandrel fallacy: "I haven't really had time to determine empirically whether or not something has a function so I'll conclude that it can't possibly have one" (Dunbar 2012, p. 201). Still, it is hard to know what evidence could disconfirm the possibility that, at least in some contexts, animals play for pleasure.

2.2. Play as Performance

Animals may play not (only) because play is rewarding but also, paradoxically, because play is costly, both in terms of time and energy and in terms of risks to life and limb (Harcourt 1991, Sharpe et al. 2002). Animals (including human children) play only when they are healthy, well fed, and safe, and they stop playing when they are injured or under stress (Alessandri 1991, Burghardt 2005, Cicchetti & Toth 1995, Dawkins 2006, Fagan 1981, Fagot & Kavanagh 1991, Fraser & Duncan 1998, Held & Špinka 2011, Lawrence 1987, Martin & Caro 1985, Špinka et al. 2001).[1] Since play is both costly and easy to observe, it may function as an honest signal of health and fitness (e.g., **Figure 1*b***).

Moreover, play is also a sensitive signal: It drops off quickly in response to real and perceived threats, recovers quickly in their absence, and flourishes in resource-rich environments (Fagan 1981, Panksepp & Burgdorf 2010, Thornton & Waterman-Pearson 2002). Thus, for instance, baboons' play closely tracks annual rainfall (Barrett et al. 1992), and meerkats' play doubles relative to controls when their food is supplemented (Sharpe et al. 2002). Insofar as predators may be less likely to attack (and conspecifics more likely to mate) with animals who look like they are uninjured, well fed, and vigorous, play might be favored by both natural and sexual selection.[2] We refer to the idea that play might function as a signal of fitness as play for performance.

[1]There are some exceptions, however, where increased stress leads to increased play (e.g., Barnett & Storm 1981; Gray 2013; for a discussion, see Lillard 2015). Kittens and rat pups weaned earlier than usual, and yearling rhesus monkeys deprived of care by the birth of a sibling, play more than their age-mates, arguably as a step toward increased independence (Bateson et al. 1981, 1990; Devinney et al. 2003; Smith 1991; see Held & Špinka 2011 for discussion).

[2]Since play is associated with juveniles, it might be difficult to imagine a role for it in mate selection, but in fact play persists into adulthood in humans cross-culturally (Roberts & Sutton-Smith 1962) as well as in most other animals observed, including rhesus monkeys (Breuggeman 1978), horses (Hausberger et al. 2012), cats (Hall & Bradshaw 1998), cormorants and herons (Sazima 2008), otters (Beckel 1991), bottlenose dolphins

Erratum

Figure 1

Examples of the kinds of behaviors associated with each of the noncognitive accounts of play. (*a*) Play for pleasure. A dolphin blowing bubble rings (McCowan et al. 2000). (*b*) Play for performance. A springbok showing off its youth and fitness by pronking (bouncing off all four legs). (*c*) Play for peacemaking. Play fighting in wolf cubs possibly as a low-cost way to establish dominance hierarchies. Photo in panel *c* by Zechariah Judy.

2.3. Play for Peacemaking

Play might enhance fitness, not simply advertise it. In particular, researchers have suggested that social play might reduce within-group aggression and increase within-group coordination. Pack and herd animals who can evaluate one another's strength and establish dominance hierarchies through play might be more likely to avoid riskier fights that could weaken the group as a whole (Dolhinow 1999; Palagi 2006, 2008; Panksepp 1981; Pellis & Iwaniuk 2000; Pellis & Pellis 1991; Smith 1982; Thompson 1998; Zimen 1982). Additionally, attention to the metacommunicative signals used in play (exaggerated calls and postures, repeated movements like headshaking and tail-wagging; Bekoff 1972) might support social attunement and greater cooperation in hunting prey and fending off predators (**Figure 1*c***).

However, although the idea that "animals that play together stay together" (Bekoff 1974) has been influential (Baldwin & Baldwin 1974, Bekoff & Byers 1985, Berman 1982, Drea et al. 1996, Gaines & McClenaghan 1980, Hall 1968, Holmes 1995, Jay 1963, Lee 1982, Panksepp 1981, Poirier 1969, Poirier & Smith 1974), evidence for this claim is mixed. Some research has found that play (e.g., in coyote pups) is inversely correlated with sibling aggression (Drea et al. 1996), but many other studies that have looked for relationships between play and positive social outcomes have failed to find them. Thus, for instance, individual differences in juvenile play have no effect on within-group aggression or social dispersion in wallabies (Watson 1993), squirrel monkeys (Baldwin & Baldwin 1974), wolves (Cordoni 2009), rats (Pellis & Iwaniuk 1999), or meerkats (Sharpe 2005, Sharpe & Cherry 2003). Arguably, however, play might still have species-level effects on peacemaking insofar as highly intelligent social species often display high levels of social cohesion despite also having high levels of within-species aggression (De Waal 1986).

3. COGNITIVE ACCOUNTS OF PLAY

3.1. Play for Practice

Thus far, we have discussed noncognitive accounts of play; we now turn to the idea that play supports learning. In all of modern psychology, perhaps few claims are so uncontroversial—and so hard to substantiate. Parents, educators, and researchers alike believe that play in early childhood supports learning (Berlyne 1969, Bruner et al. 1976, Groos 1901, Piaget 1962, Singer et al. 2009, Vygotsky 1962), and across species, it is clear that smarter, more behaviorally flexible species play more (Bjorklund 1997, Groos 1898, Pellegrini et al. 2007). Nonetheless, establishing specific relationships between play and learning remains a challenge.

The most straightforward way that play could support adult behavior is not through learning but by increasing physical fitness (Bekoff 1988, Byers 1998, Fagan 1981). However, because exercise-induced effects of fitness are transitory (e.g., Byers 1998), an alternative possibility is that play helps juveniles master locomotor skills critical to adulthood (play as practice) (Groos 1898; see also Bekoff & Byers 1998, Burghardt 2005, Fagan 1981, Pellegrini et al. 2007). This seems especially plausible with respect to the complex motor skills involved in hunting or using tools. Thus, kittens might pounce on strings, chimps and crows play with sticks, and otter pups play with rocks in order to, respectively, be better able to catch mice, extract ants and larvae from crevices, and crack mollusk shells as adults (**Figure 2**) (Caro 1995, Humle 2006, Inoue-Nakamura & Matsuzawa 1997, Nishida & Hiraiwa 1982, Rutz et al. 2010). Consistent with the idea that play is

(Kuczaj & Eskelinen 2014), and humpback whales (indeed, the latter two have been observed playing with each other; Deakos et al. 2010.)

Figure 2

Play for practice. Rock juggling in otter pups possibly fosters the motor skills needed to use rocks to open mollusks as an adult (though evidence that this play really does support adult skills has been hard to come by; Allison et al. 2020).

preparation for adult behavior, children, cross-culturally, are given scaled-down, often nonfunctional versions of adult tools as playthings (e.g., Gusinde 1931, Healey 1990, MacDonald 2007, Watanabe 1975), and babies spend many hours manipulating objects before they master the use of even simple tools like spoons or rakes (Connolly & Dalgleish 1989; Lockman 2000; McCarty et al. 1999, 2001; Piaget 1952).

However, although the idea of play as practice for adult life is intuitive, there is surprisingly little evidence that play in juveniles correlates with skill in adults. Thus, for instance, kittens raised without toys grow up to hunt as well as kittens surrounded with them (Caro 1980), the amount of play meerkats engage in as youngsters is uncorrelated with their success in hunting or in territorial disputes as adults (Sharpe 2005), and otters who juggle rocks more frequently are not any faster at extracting food (Allison et al. 2020). Similarly, although there is considerable evidence that developmental delays and disorders affect exploratory play in humans (de Almeida Soares et al. 2012, de Campos et al. 2013, Kaur et al. 2015, Kavšek 2004, Kavšek & Bornstein 2010, Kopp & Vaughn 1982, Koterba et al. 2014, Loveland 1987, Ruff et al. 1984, Sigman 1976, Wilson 1975, Zuccarini et al. 2016), there is only weak evidence that typical exploratory behavior correlates with later outcomes (Bornstein et al. 2013, McCall & Carriger 1993, Muentener et al. 2018, Raine et al. 2002, Viholainen et al. 2006). Moreover, the further removed the juvenile behavior is from motor coordination, the less compelling the relationship between play and adult skills becomes. A recent comprehensive review, for instance, found no strong evidence for causal relationships between pretend play and cognitive outcomes for any of the areas (intelligence, creativity, problem solving, theory of mind, language, executive function, and emotion regulation) for which links had been proposed (Lillard et al. 2013). Nonetheless, some skills, especially those related to implicit skill learning (i.e., playing instruments, playing sports), are clearly easier to learn before late

Erratum >

adolescence than later in life (Janacsek et al. 2012). Thus, for at least some kinds of behaviors, the particular activities practiced in juvenile play are indeed likely to have enduring impacts.

3.2. Play for Prediction and Plans

The idea of play as practice suggests that most of the benefits of play are incurred in adulthood. However, the most influential current accounts of the relationship between play and learning suggest that play behaviors are motivated by learners' moment-to-moment epistemic curiosity. Furthermore, these accounts suggest that information gained in play has online effects in reducing learners' uncertainty and in increasing their ability to predict events in the world. There have been several excellent discussions of epistemic curiosity, exploration, and self-directed learning in the past decade (Gottlieb et al. 2013, Gureckis & Markant 2012, Jirout & Klahr 2012, Kidd & Hayden 2015, Silvia 2012), so we do not attempt another comprehensive review here. Instead, we focus on a few key findings in the developmental literature and highlight relevant connections to work in ethology, artificial intelligence (AI), robotics, and computational cognitive science.

In the developmental literature, the link between play and learning has focused largely on connections between exploratory behavior and children's causal reasoning. The earliest form of exploration we can measure is visual exploration, and looking-time methods have yielded rich accounts of infant perceptual and cognitive abilities (for reviews, see Aslin 2007, Haith 1980). Like many other animals, infants preferentially look at stimuli that are novel (Fagan 1970, Fantz 1964, Saayman et al. 1964), perceptually salient (Civan et al. 2005, Kaldy & Blaser 2013), and relatively complex (Brennan et al. 1966, Cohen 1972, Thomas 1965), and this selective attention may help infants learn statistical properties across events ranging from patterns of shapes to phonetic alternations (Fiser & Aslin 2002; Kirkham et al. 2002; Maye et al. 2002; Saffran et al. 1996, 1999; Saylor et al. 2007).

Infants' visual attention is not only stimulus driven; infants look longer at events that violate their expectations of the world (for reviews, see Spelke 1985, Spelke et al. 1992). Researchers using violation-of-expectation and preferential looking paradigms have made fundamental discoveries about infants' early representations of objects and forces (Baillargeon 1987; Baillargeon et al. 1985; Kim & Spelke 1992, 1999), number (McCrink & Wynn 2004, Wynn 1992), probability and sampling (Xu & Garcia 2008), agents and goals (Liu et al. 2017, Luo 2011, Onishi & Baillargeon 2005, Woodward 1998), social interactions (Hamlin et al. 2010, Powell & Spelke 2013), and emotions (Skerry & Spelke 2014, Wu & Gweon 2019, Wu & Schulz 2018).

Of course, visual exploration does not constitute play, per se. But by 6 months of age, infants begin to manually explore objects and the physical environment. While earlier researchers thought that infant exploratory play might be repetitive and perseverative (e.g., Piaget 1954), recent work suggests that infants selectively explore objects that appear to violate their naïve theories, and explore in ways specific to the apparent violation (for a review, see Stahl & Feigenson 2018). For instance, infants tend to drop toys that appear to violate gravity but bang toys that appear to violate solidity (Stahl & Feigenson 2015). Moreover, infants do not engage in this kind of exploration if the apparent violation can be explained away (e.g., a toy appears to pass through a solid wall, but the wall is then turned to reveal a gap; Perez & Feigenson 2020).

Children's exploration becomes increasingly sophisticated after infancy and throughout the preschool years (Pelz & Kidd 2020). Toddlers can use covariation evidence to determine the probable cause of failed actions and seek help or explore accordingly (Gweon & Schulz 2011), and they will selectively explore objects depending on whether evidence for the extension of object properties was drawn randomly or selectively (Gweon et al. 2010). Children selectively explore evidence that violates their prior expectations (Bonawitz et al. 2012, Schulz et al. 2008b), and both toddlers

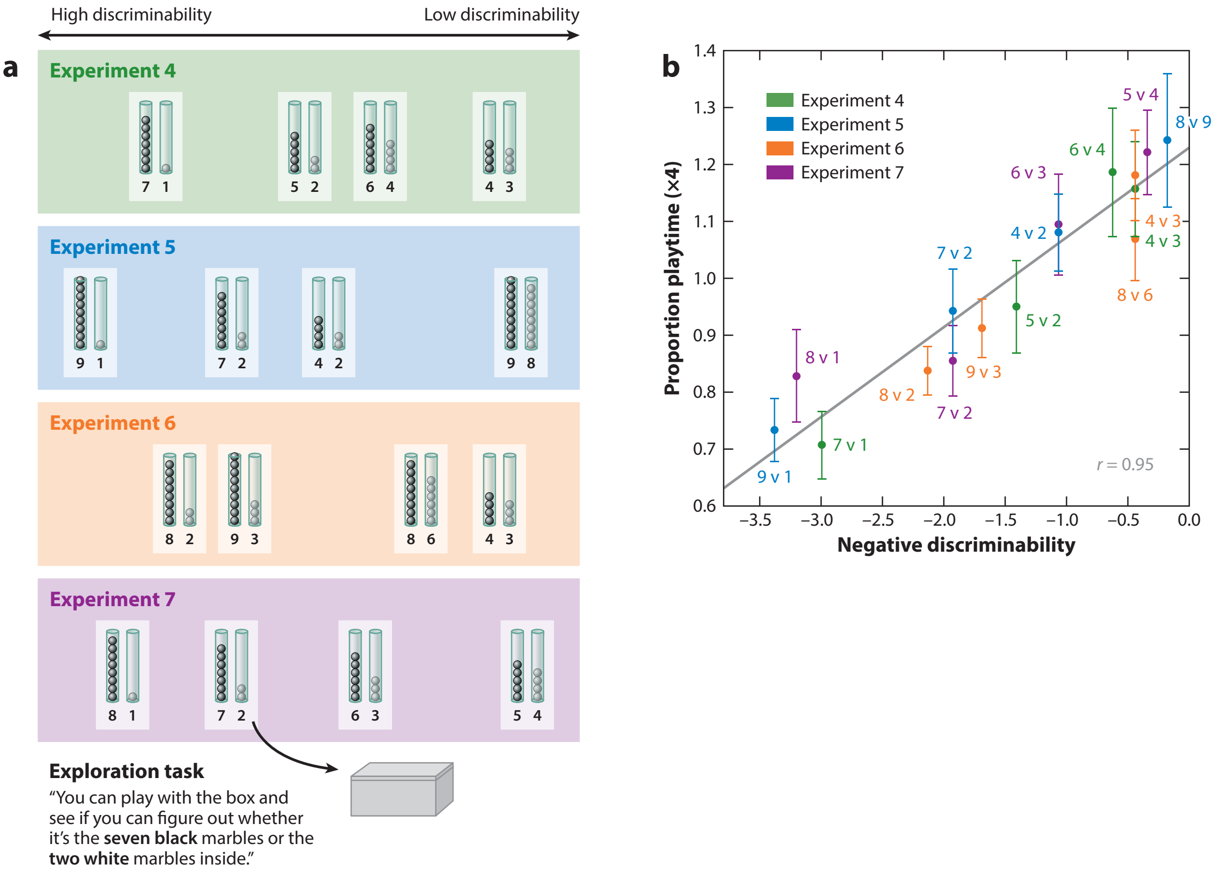

Figure 3

Play for prediction and plans. (*a*) Children shook a box to guess how many marbles were inside. (*b*) Their exploration time tracked the difficulty of discriminating between the heard and unheard alternatives in a remarkably fine-grained way (Siegel et al. 2020). Abbreviation: v, versus. Figure adapted from Siegel et al. (2020).

and preschoolers will selectively search for unobserved causes given theory-violating evidence (Muentener & Schulz 2014, Schulz et al. 2008a, Schulz & Sommerville 2006, Sobel et al. 2007). Preschoolers also explore and engage in active hypothesis testing given ambiguous or confounded evidence (Cook et al. 2011, Schulz & Bonawitz 2007, van Schijndel et al. 2015), and recent research suggests that children's exploratory play is closely calibrated to their uncertainty, quantitatively varying with the difficulty of discrimination problems (**Figure 3**) (Siegel et al. 2020).

Moreover, children's exploratory play supports causal learning (McCormack et al. 2015, Schulz et al. 2007); even 2- and 3-year-olds can discover abstract relations, including hierarchical causal structures, in free play (Sim & Xu 2017). Children attend more to the effects of their own interventions than observed evidence (Fireman et al. 2003, Kushnir & Gopnik 2005, Kushnir et al. 2009), and in some cases, children may learn better through free play than through observation alone (Sobel & Sommerville 2010). Moreover, the link between play and causal reasoning is not limited to exploratory play; some research suggests that children's pretend play also supports causal and counterfactual reasoning (Buchsbaum et al. 2012; see also Gopnik & Walker 2013, Kavanaugh & Harris 1999, Weisberg & Gopnik 2013).

Finally, children integrate causal and social information in their play. Both preschoolers' and toddlers' exploratory play is sensitive to whether evidence is provided accidentally or pedagogically (Bonawitz et al. 2011; Butler & Markman 2012, 2014; Jean et al. 2019; Shneidman et al. 2016) as well as to whether evidence is selectively withheld (Gweon et al. 2014). Preschoolers explore more when adults provide information about the function of toys in the form of questions rather than statements (Yu et al. 2018), and they selectively use the more informative of prior knowledge or social cues to guide their exploration (Luchkina et al. 2018). Children also use the results of their own exploration to teach others (Gweon & Schulz 2018), and guided play by teachers supports children's learning while increasing their engagement (Bustamante et al. 2020, Fisher et al. 2013, Weisberg et al. 2013). Thus, although children's play might often appear random or haphazard, collectively these studies suggest that children's play is connected to principles that could support learning and discovery in early childhood (for a review, see Schulz 2012b).

We restrict our review to the literature on children. Doing justice to the research on exploratory behavior and learning in nonhuman animals and in artificial agents is beyond the scope of this article. However, we want to highlight three common threads that unite discussions of play and learning across developmental, ethological, and computational approaches.

First, the motivation to seek new information is widespread. Humans do it—so do crows and chimps, octopi and orangutans[3] (Mather & Anderson 1999, Welker 1956, Wimpenny et al. 2010). Even the search behavior of animals as simple as moths and roundworms can be characterized by models of maximally informative foraging (Calhoun et al. 2014, Vergassola et al. 2007). Moreover, the motivation to explore is robust. Animals will forgo immediate, tangible rewards and incur costs, including physical pain, to gain information (e.g., hungry and thirsty rats will delay eating and drinking to explore new terrain, and rats conditioned to fear an electrified grille will cross it to explore; Nissen 1930, Zimbardo & Montgomery 1957). Some of this behavior can be characterized as instrumental behavior in which forgoing immediate rewards enhances overall gains in the longer term. But there is also a wealth of evidence that animals value information in its own right, even when it serves no instrumental end (Bennett et al. 2016, Blanchard et al. 2015, Gottlieb & Oudeyer 2018, Vasconcelos et al. 2015; see also Pellegrini et al. 2007, Špinka et al. 2001).

Second, while the motivation to explore is early emerging, widespread, and robust, it is not indiscriminate. Learners do not attend merely to the degree to which information is novel or unpredictable; if they did, they would spend much of their time exploring stimuli that are novel and hard to predict but from which nothing meaningful could be learned (e.g., the pattern of raindrops falling on the ground). Instead, learners, including human infants, set their own goals for learning, selectively attend to information that is learnable, and decide what and whom to learn from (e.g., Begus et al. 2016, Gerken et al. 2011, Kidd et al. 2012). Although much remains to be understood about how these goals are established and constrain learning (see discussion in Section 4.3), there is broad consensus that learners are most motivated to explore when there is neither too much information to be learned nor too little (Begus et al. 2016, Berlyne 1960, Csikszentmihalyi 1990, Dember & Earl 1957, Gerken et al. 2011, Gottlieb et al. 2013, Kidd et al. 2012, Kinney & Kagan 1976, Loewenstein 1994, Oudeyer et al. 2007, Schmidhuber 2013)—a so-called Goldilocks effect that has been attributed variously to the learners' representation of the surprisal value of stimuli (Kidd et al. 2012), the rate of change in their own learning (Gottlieb et al. 2013), the size of the gap in their current knowledge (Loewenstein 1994), or the amount of structure in the stimuli (Gerken et al. 2011).

[3]Interestingly, wild orangutans are far more neophobic than neophilic; only in captivity do orangutans show high rates of exploration.

Finally, in recent years, there has been substantial progress in thinking about the computational and neural substrates that might subserve effective information seeking, especially in contexts where rewards are sparse (Burda et al. 2019, Chitnis et al. 2020, Gottlieb et al. 2013, Oudeyer & Smith 2016, Oudeyer et al. 2007, Pathak et al. 2017, Schmidhuber 2013). The various approaches differ both between and within fields, but they share a commitment to curiosity-driven exploration as a means of gaining information, reducing uncertainty, and improving prediction and control. In this sense, all these accounts attest to the idea of play for prediction and plans.

4. DISTINCTIVELY HUMAN PLAY

These five accounts—play for pleasure, play for performance, play for peacemaking, play for practice, and play for prediction and plans—all cover a broad range of behaviors and, as discussed above, are not mutually exclusive. A 6-month-old baby might grasp a rattle for the pleasure of holding something tightly in his hand and shake it vigorously, conveying health and fitness. The sight and sound might amuse others and strengthen social bonds. In exercising his fine-motor development, the play might make him a better tool user as an adult. And by coming to anticipate the sound made by his shaking, he might develop better predictive models of the world and be able to organize his own behavior into increasingly complex sequences.

In short, even if no single one of these accounts does justice to the richness of play, collectively they might seem fairly comprehensive. But the limitations of these accounts, and the degree to which play remains elusive, may become more evident when, 30 months later, that same child, armed with a kitchen strainer, takes that rattle, buries it in a hole, covers it with leaves, and, when asked what he is up to, explains that he is building a trap for a velociraptor because when the velociraptor steps on the leaves, the rattle will make a noise, and then he can trap it with the strainer.

The example is frivolous, but the point is not. Although the opportunities, content, and resources available for children's play vary cross-culturally, the richness and variability of play are a human universal (Edwards 2000; Gosso 2010; Gosso et al. 2007; Lancy 2002, 2007; Nwokah & Ikekeonwu 1998; Schwartzman 1986; Singer et al. 2009). The kind of elaborated behavior, seamlessly integrating elements of pretend and exploratory play,[4] depicted in the velociraptor example is not the exception but the rule in human play after toddlerhood.

Critically, there is no sense in which play like this is merely a generalization of the kind of play characterized by the accounts above. This kind of play is often solitary, so it is unlikely to be useful for performance or peacemaking; nor does it seem driven primarily by a pleasurable sensorimotor component. One could suppose that the child is practicing adult activities, such as trapping mice, but it stretches credulity to suppose that this kind of play will actually help him build a better mousetrap. And this kind of play defeats even the most cognitively sophisticated account we have reviewed: play for prediction and planning. The child already knows the rattle makes noise. He also already knows that the leaf pile will conceal the rattle; that is why he is hiding it in there. To play the way he is, he has already had to access abstract concepts of concealment, detection, and

[4]In the discussion below (Sections 4.1–4.5), we draw no distinction between exploratory and pretend play largely because it is not obvious that children do. A child pretending to trap a velociraptor may be exploring whether the rattle can be used to dig a hole in the leaves; a child playing with stacking cups may be making a dinner table for his toy hippopotamus. For our purposes, what different forms of distinctively human play have in common is more important than what distinguishes them. Also, in the remainder of this review, unless otherwise specified, we use the term "play" to mean "distinctively human play of the kind that emerges after toddlerhood." But nothing that follows should be taken as disputing the prevalence of other kinds of play or invalidating any of the ways of accounting for those kinds of play reviewed above.

containment and coordinate them into complex plans. And, needless to say, the activity is unlikely to teach him anything he doesn't already know about velociraptors.

So, what is the child doing? And what, if anything, does it have to do with distinctively human curiosity and cognition? The remainder of this review is an attempt to answer these questions. To foreshadow, we suggest that distinctively human play involves manipulating our own utilities such that we invent problems for ourselves. We offer some preliminary evidence for this hypothesis, showing that, even given identical goals, children's exploratory behavior differs from their exploratory play; children violate normal utilities only when they are playing. We then briefly digress from play to explain why problems, in general, might be valuable for hypothesis generation. We then return to the topic to propose that the sustained engagement children show in play, independent of any obvious reward (including information gain), is a hallmark of distinctively human curiosity: a curiosity that depends on progress not in learning but in thinking. Finally, we suggest that the idiosyncratic, arbitrary nature of the problems set in play, and the often flimsy, inadequate solutions generated, may be offset by the fact that the ideas generated in play can be decoupled from the problems that inspired them and be valuable in their own right. Throughout this section, the account we offer is speculative, relying more on conjectures than on data. But although we approach the topic somewhat playfully ourselves, we do so with the serious intent of trying to grapple with what is distinctive about human play, curiosity, and cognition.

4.1. Play for Problems and Proposals

As described above, scientists can use play as a dependent measure of children's sensitivity to many factors connected to information gain: violations of intuitive theories (Bonawitz et al. 2012, Legare 2014, Schulz et al. 2008b), the information structure of tasks (Ruggeri et al. 2019), the ambiguity of hypotheses (Cook et al. 2011, van Schijndel et al. 2015), and the discriminability of data (Siegel et al. 2020). Arguably, however, these tasks tell us a great deal about children's learning but relatively little about children's play. That is, although we, as adult scientists, can use play to assess children's sensitivity to uncertainty and expected information gain, that is not necessarily the best characterization of what children use it for.

Some prima facie evidence that this is the case is the notorious gap between play as we study it in the lab and play as it exists in the wild. It takes considerable effort and bespoke experimental designs to contain the variability and arbitrariness of children's play sufficiently for it to be used as a measure of information gain. In research on play as a form of rational learning, that variability is treated as noise, but children's propensity to adopt idiosyncratic goals may be what distinctively human play is all about. More broadly, we propose that many kinds of distinctively human play—from catching velociraptors to building rocket ships to playing soccer or chess—involve creating problems for ourselves. We suggest that the most salient characteristic linking all these forms of play is the extent to which we intervene on our own utility functions and willingly incur unnecessary costs to achieve arbitrary rewards.

4.2. Decoupling Utilities from Utilitarian Ends

The degree to which play involves manipulated utility functions can perhaps be best appreciated in directly comparing children's exploration with their exploratory play. Although much of the literature on play and learning (including most of the senior author's own research) has treated these as equivalent behaviors (i.e., play as rational exploration), we believe this is misleading. Specifically, in a recent study (Chu & Schulz 2020), we gave 4- and 5-year-old children closely matched retrieval and exploration tasks which differed only in whether children were asked to achieve a goal or asked to play and achieve the goal. Thus, for instance, children were brought to the door

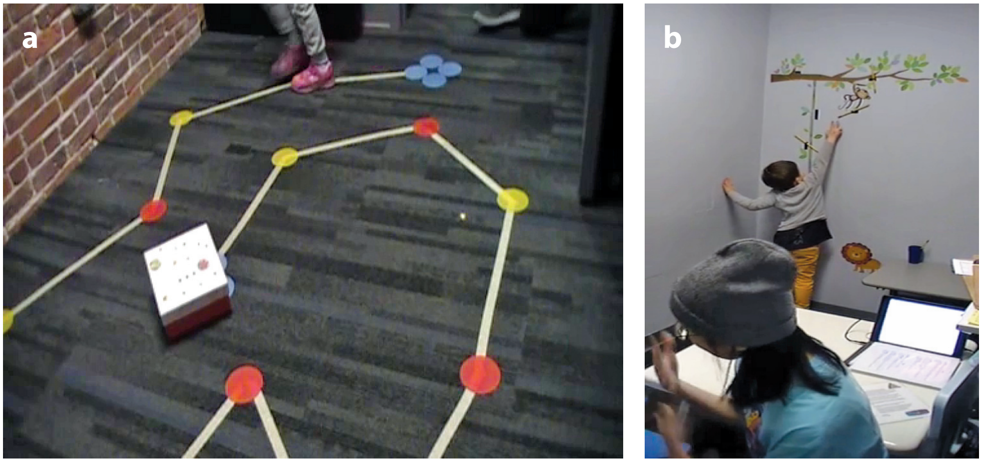

Figure 4

Play for problems and proposals. Preschoolers were told to play and retrieve objects (Chu & Schulz 2020). In play, children (*a*) walked in a spiral to get to a box of stickers in the middle of the room rather than running straight for it and (*b*) reached for out-of-reach pencils and ignored the easily accessible pencils in a cup on the table. When asked to retrieve the same objects for instrumental reasons, children did the opposite: going straight to the box of stickers and the pencils in the cup.

of a room with a spiral design on the floor and a box at the center of the spiral. In one condition, the children were told, "There are stickers in that box. Can you go in there and try to get one?" In the other, they were told, "There are stickers in that box. Can you play in there and try to get one?" In the former case, children ignored the spiral design on the floor and walked in a straight line to the box in the middle of the spiral; in the latter, they not only walked around the spiral before getting the stickers but sometimes did so twice or walked around backwards (**Figure 4*a***). In a different experiment, children were introduced to a room containing a table with a cup of pencils on it and a stenciled tree on the wall with pencils velcroed to the branches just out of the children's reach. When told, "I need a pencil to fill out this form. Can you go over there and try to get a pencil?" children went directly to the cup. But when told, "I need to fill out this form. While I'm doing that, can you play over there and try to get a pencil?" children went to the stenciled tree and not only jumped up to get a pencil but then, having retrieved one pencil, jumped up and down again repeatedly to try to get more pencils near the top of the tree (**Figure 4*b***). Children showed the same pattern in exploration tasks. Given a choice between 1 drawer on the left and 12 drawers on the right, children reliably preferred the smaller search space when they were told to find a ball to use in another game and reliably preferred the larger when told it was a hide-and-seek game ("I'm going to hide the ball, and you get to find it. Do you want to play over there or over there?").

In the sense that human play involves manipulated utility functions, all play is pretend play; when the costs or rewards are real, we are no longer playing. And yet, it would be a mistake to think that in play, children behave either randomly or irrationally. Even when children opted for the unnecessarily costly goal, they behaved efficiently with respect to that goal (adhering close to the spiral path, jumping directly toward the pencils, searching the boxes in sequential order).

Thus, we suggest that in play, children's behavior is not only boundedly rational (e.g., limited by children's information processing constraints; Simon 1955) but also conditionally rational: rational with respect to a manipulated utility function.

Of course, humans are not the only animals to engage in self-handicapping behavior during play. Primates will try to balance themselves on unstable branches, and wolves and dogs will bow low rather than towering to attack in play fighting. Researchers have proposed that this kind of play prepares animals for unusual, unexpected events and may provide them with experience improvising solutions (Špinka et al. 2001). We suggest that a violation of normal utility functions characterizes human play as well but in much more far-reaching ways. We not only incur unnecessary costs but also flexibly fix our own arbitrary rewards by setting a vast range of novel goals.

4.3. How Problems Structure Their Own Solutions

But surely there are enough problems in the world. Why should we make new ones for ourselves? We believe novel problems and goals[5] may be critical to human cognition because problems constrain search, and narrowing the search space sufficiently to generate new hypotheses is arguably, far more than learning per se, the hard problem of cognition. To quote from a recent workshop on program induction (Bramley et al. 2018, p. 5): "Coming up with the right hypotheses and theories in the first place is often much harder than ruling among them. How do people, and how can machines, expand their hypothesis spaces to generate wholly new ideas, plans, and solutions?"

The idea that goals could improve learning and planning is widely recognized in AI and robotics. Many approaches to engineering intrinsically motivated autonomous agents involve having agents establish their own curricula for goal-directed learning (e.g., Agrawal et al. 2016, Chitnis et al. 2020, Kaelbling 1993, Lynch et al. 2020, Sukhbaatar et al. 2018). However, the current proposal differs from these accounts in our commitment to the idea that the goals generated in play might not translate into reduced uncertainty or prediction error, or even the achievement of the goals themselves. (Indeed, there is no obvious sense of what it might mean for a child to successfully trap an imaginary velociraptor.) Rather, the value of the problems posed in play might be simply in generating the new thoughts and plans themselves. Liberated from any real-world goal—even the goal of fulfilling its own goals—human play may be less a means of gaining information than a means of increasing innovation.

But to understand how problems contain the kind of information that could support the generation of new ideas, we must leave play behind for a moment and turn to problems themselves. To start, let us consider the information available in question words (**Figure 5**).

Before you know what someone is asking, let alone before you can answer their question, you already know a lot about what the answer has to look like. Answers to *who*-questions are likely to refer to a social network; *where*-questions, a map; *when*-questions, a timeline; *what*-questions, a category structure; *which*-questions, the intersection of a Venn diagram; *how*-questions, a circuit of some kind; and *why*-questions, a causal network. Each additional word in a query imposes further constraints, further narrowing the search space for the solution. Even a single additional function word can do a lot of work: "Why does. . .?" will likely be answered by a rule or empirical generalization; "Why did. . .?" will have to account for an unexpected event; "Why can't. . .?" will have to

[5]We use the terms "problems" and "goals" interchangeably in the remainder of this review, on the understanding that if you have a goal, then the problem is how to achieve it. Problems and goals differ chiefly in that when your problem is a query, your solution can take the form of a hypothesis or proposal; when your problem is how to achieve a goal, the solution must take the form of a plan. For our purposes, the key point is that in both cases, the information in the problem itself constrains the search for solutions.

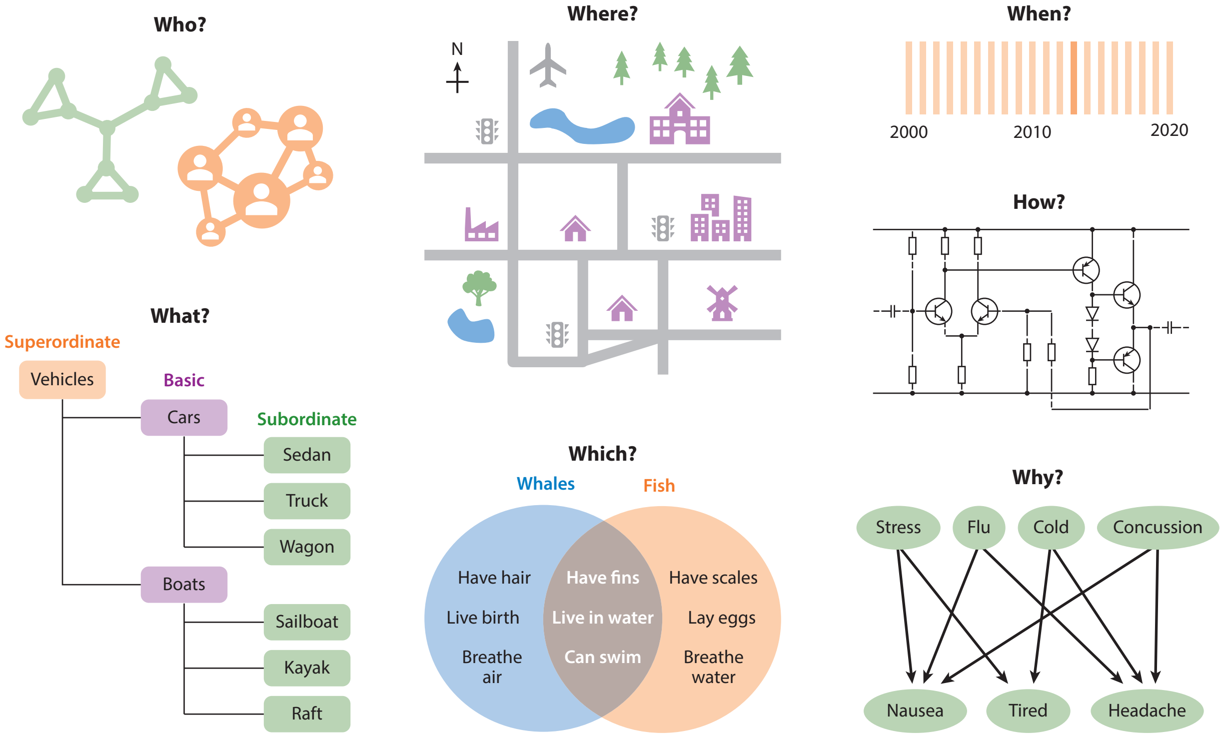

Figure 5

Queries contain information constraining their own answers, independent of content domain.

explain why something seemingly possible or permissible is not. Each word of the query imposes different constraints on the possible responses.

Knowing the form of a question does not mean you can answer it, but at least it will get you in the right ballpark. Rejecting wrong answers to a question may be far more tractable than evaluating answers that are "not even wrong" (e.g., "1774" is the wrong answer to "When did the United States declare independence from Great Britain?" but it is not even wrong in response to "Why did the United States declare independence from Great Britain?").

While representing the abstract space of answers to a query might seem to require sophisticated reasoning, as early as 2 and 3 years, young children are sensitive to the form of questions and what might count as answers (Bloom et al. 1982; Callanan & Oakes 1992; Frazier et al. 2009, 2016; Kemler Nelson et al. 2004). And despite preschoolers' robust preference for reliable, confident informants (e.g., Harris et al. 2018, Jaswal & Malone 2007, Koenig et al. 2004), children will accept tentatively advanced conjectures that are possible answers to a question over confidently asserted, known facts that are not (Chu & Schulz 2018). Thus, simply posing a question might allow learners to start generating plausible solutions (see Chu & Schulz 2020, Schulz 2012a for discussion).

Critically, rich, structured constraints are not only a property of queries expressed in language; all kinds of problems are rich in information. To the degree that we can represent abstract properties of our problems and goals (e.g., "I need something that is smaller than this but the same shape"; "I want this to go up and down again and again"; "I need something that gets bigger fast"), these representations (e.g., proportionality, cyclic variation, nonlinear growth) could constrain the search for solutions and plans, independent of content domain. Previous research suggests that 4- and 5-year-olds can use abstract properties like proportionality and cyclicity to constrain hypotheses about probable causes of observed effects (Magid et al. 2015, Tsividis et al. 2015). Thus, abstract representations of the form of problems, together with their specific content, might provide sufficient constraints for children to generate new ideas and plans.

4.4. Problems and Distinctively Human Curiosity

We avoid (for lack of an answer) the question of how learners recognize when problems have sufficient structure to be tractable, and simply suggest that humans are sensitive to the extent to which our problems constrain the search for solutions.[6] We propose that our recognition that a problem is tractable—in the sense of containing enough information to guide the search for a solution—inspires the kind of curiosity which can sustain long-term engagement in the face of negligible information gain.

In contrast, a large body of research on epistemic curiosity suggests that actions with high expected information gain are reinforced (or not) with respect to the degree to which they reduce online uncertainty and prediction errors. This kind of curiosity motivates human exploration and learning in any number of paradigms, including visual search tasks (Gottlieb et al. 2013, Kidd et al. 2012), bandit tasks (Daw et al. 2006), seeking information about risky choices (Blanchard et al. 2015; Bromberg-Martin & Hikosaka 2009, 2011), opening doors to reveal hidden objects (Jirout & Klahr 2012), learning the answer to trivia questions (Loewenstein 1994), and autonomous artificial agents' exploration of novel spaces and novel objects (e.g., Burda et al. 2019, Florensa et al. 2017, Forestier et al. 2017, Friston et al. 2015, Little & Sommer 2013, Martius et al. 2013, Oudeyer & Smith 2016, Pathak et al. 2017, Schmidhuber 2010). Indeed, the virtue of such accounts is that they account for exploration broadly and extend to the kinds of epistemic curiosity that might apply across many intelligent agents.

But if epistemic curiosity tracks our progress in learning (e.g., Oudeyer & Smith 2016, Oudeyer et al. 2007, Schmidhuber 1991)—the degree to which our predictions improve and our uncertainty decreases—it is hard to explain the kind of sustained engagement that characterizes much of our experience as humans. Humans can be fascinated both by questions we will probably never answer ("Who would you be if you had a brain transplant?" "What would you do if you had a billion dollars?") and by questions that may take years or even lifetimes to answer ("Can we find particles of dark matter?"). We suggest that this kind of epistemic curiosity is consistent with an ability to track not only the rate at which we are learning but also the rate at which we are thinking. To the degree that we can continue to generate speculations, hypotheses, and partial plans, we may feel like we are making progress on a problem even if there is no evidence to assess that progress. The degree to which a problem or goal supports the generation of plans and hypotheses may itself be motivating—whether or not the plans actually bring us closer to attaining the goal and whether or not those hypotheses reduce prediction error. That is, we propose that in humans, intrinsic reward is tied to the ability to act and think, not merely the consequences of our actions and thoughts.[7]

[6]As the reader might have observed, we also avoid (again, because we have no answer) the question of how learners generate new goals and problems.

[7]These ideas are loosely connected to ideas about empowerment in the reinforcement learning literature—the idea that organisms are intrinsically motivated to maximize the degrees of freedom they have for acting on their environment (Klyubin et al. 2005, Salge et al. 2013). However, empowerment indexes the extent to

Precisely because this kind of engagement is no guarantee of increased learning, it is quintessentially playful. Indeed, we believe children's often rapt absorption in solitary play suggests the intrinsic reward associated merely with thinking. Of course, there is a very wide gap between inventing plans to catch nonexistent velociraptors and inventing plans to catch possibly existent weakly interacting massive particles. But humans are the only creatures that do both, and to be the kinds of creatures we are—learners whose learning goes far beyond prior knowledge and data—we may have to value problems that engage us merely to the extent that we can generate possible solutions. Actual solutions—ones that reduce uncertainty and increase prediction and control—can come only later, if at all.

4.5. Unknown Unknowns and Exploring New Ways to Explore

Thus, there is a sense in which we must take the uselessness of play seriously. The problems invented in play are arbitrary and unimportant (try to trap a velociraptor, feed dinner to the hippo, get a ball through a net, use black or white stones to surround space on a grid, etc.). What seems true at face value—that burying rattles in leaves or building dinner tables for hippos serves no purpose—is, we suggest, perfectly true if by that we mean that these activities neither prepare children for adult life nor reduce children's uncertainty about anything they were uncertain about. However, although this kind of distinctively human play may be useless for many ends, we have argued that it may be useful for thinking; even frivolous problems contain enough structure and information to allow us to start generating new thoughts and plans. Still, one might wonder, what is the use of thinking frivolous things? Especially when, by many criteria, the ad hoc solutions we generate in response to arbitrary problems we invent are themselves bad ones (cf. the plan for trapping the velociraptor).

One reason that the triviality of the problems and the badness of our proposed solutions may not matter is that the ideas we generate can be decoupled from the problems that inspired them. Indeed, one of the striking and characteristic features of children at play is that they often spend much of the day playing and then abandon their plans both without ever achieving their goals and without any apparent regret. When a 7-year-old decides to build a spaceship and fly to Mars, she may have very decided opinions about what to do and how to do it; spend hours tinkering with tinfoil, tape, and a hairdryer; but then abandon the whole setup in the backyard after half a day's work without a flicker of dismay the instant the ice cream truck rolls by.

As discussed above, we suggest that what matters about the child's play is neither the unachievable goal nor the half-baked solution but rather the fact that the goal contained just enough structure to generate new ideas. The little that the 7-year-old knew about rocket ships (e.g., that they are large, shiny, and propelled by something) was sufficient to support thinking and planning. But although a hairdryer is a very bad way to move a rocket ship, it may not be a bad way to make something move in general. The idea can be decoupled from the goal that motivated it and might turn out to be useful in unrelated contexts (e.g., for extracting a retainer from under a bookshelf).

Critically, it is not the case (on our account) that the child learned that hairdryers could propel things through play. If it had not occurred to the child that the hairdryer could propel things, she would never have swiped it from her mother's drawer. Rather, the point is that the child would have been unlikely to think about the propulsive capabilities of hairdryers but for the fact that she

which an organism can influence its environment and register its influence. The current account, by contrast, is predicated not on the idea of control but rather on the capacity for thought and action itself (independent of any downstream effects of those thoughts and actions). That is, we suggest that the intrinsic value of a goal is its ability to generate a plan and that the intrinsic value of a problem is its ability to generate possible solutions.

wanted to build a rocket ship and needed something that would serve that purpose. Posing the problem she did supported thinking of the solution she did. Once thought of, the solution can take on a life of its own. Thus, the idiosyncratic, arbitrary nature of play may be valuable because each new problem and goal imposes unique constraints that lead to unique plans and solutions—any of which may be repurposed. One reason our motivational system may be as rich as it is, is that our ability, as a species, to want anything at all lets us explore a vast space of possible plans and ideas.

More broadly, as we have reviewed, all kinds of animals engage in exploration and learning. What might be distinctive about human play is that people not only exploit their existing knowledge about how to explore (i.e., by acting efficiently to maximize expected information gain) but also explore new ways to explore. A sure way to do that is to intervene on normal utility functions, assigning arbitrary rewards and accepting unnecessary costs. But, again, why explore new ways to explore? Why not just explore in ways most likely to increase learning? Arguably, the reason is that epistemic goals are not the only—or necessarily even the best—way to learn new things. The world is full of unknown unknowns; as great as our uncertainty about the world is, there are even more things we don't even know we don't know. If we explored only to try to maximize expected information gain, we would miss the chance to gain unexpected information. Creating new problems with no obvious utility in themselves—playing—may be the best way to discover (genuinely) new things.

5. CONCLUSIONS AND FUTURE QUESTIONS

We have suggested that, in addition to play being valuable for pleasure, performance, peacemaking, practice, and prediction, human play may be valuable in supporting the creation of new problems and goals and that these, in turn, may support new thoughts, plans, and discoveries. However, at the moment, this account is only a speculation; many questions remain unanswered. As noted above, goals and problems might support search by constraining the hypothesis space, but we have deferred the question of how we generate new goals and problems themselves. What is it about human minds that make our utilities so flexible such that we can assign value to almost anything and willingly incur unnecessary costs? How do we distinguish ill-posed problems that insufficiently constrain search from those that are rich in structure and therefore potentially tractable? Can we formalize the information in problems and goals well enough to specify how they support the generation of new thoughts and plans? And how do we represent our own progress in thinking such that it can be a source of intrinsic reward? These and many other questions ensure that we are likely to remain curious about play for years to come.

We end by noting that scientists have puzzled over the relationship between play and development for well over a century—indeed, the philosopher and psychologist Karl Groos's (1898) formulation of "play for practice" inspired the alliterative trope here—and some of us, personally, have puzzled over the relationship between play and learning for most of our adult lives. Our enduring fascination with this topic is itself a source of some mystery. Science is supposed to answer questions. Surely there should be something dismaying about finding that the questions persist. But, as we have suggested here, we may be most curious not to the degree that we anticipate being able to answer our questions but to the degree that we realize we may never stop thinking about them. This, as much as anything, may be the signature of a human mind at play.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

Thanks are due to Josh Tenenbaum, Sheldon Huang, and members of the Goals, Problems and Stories working group for many useful discussions and for identifying some unknown unknowns we are so curious about. Thanks also go to Sophia Diggs-Gallagan, Regina Ebo, and Karolina Cabrera for feedback on an earlier version of this article.

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Annual Review of Developmental Psychology

Volume 2, 2020

Contents

Errata

An online log of corrections to *Annual Review of Developmental Psychology* articles may be found at http://www.annualreviews.org/errata/devpsych