Reconfiguring Science Education through Caring Human Inquiry and Design with Pets

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Abstract

Background: Natureculture (Haraway, 2003; Fuentes, 2010) constructs offer a powerful framework for science education to explore learners' interactions with and understanding of the natural world. Technologies such as Augmented Reality (AR) designed to reveal pets' sensory worlds and companionship with pets can facilitate learners' harmonious relationships with significant others in naturecultures.
Methods: At a two-week virtual summer camp, we engaged teens in inquiring into dogs' and cats' senses using selective color filters, investigations, experience design projects, and understanding how the umwelt (von Uexküll, 2001) of pets impacts their lives with humans. We qualitatively analyzed participants' talk, extensive notes, and projects completed at the workshop.
Findings: We found that teens engaged in the science and engineering practices of planning and carrying out investigations, constructing explanations and designing solutions, and questioning while investigating specific aspects of their pets' lives. Further, we found that teens checking and taking pets' perspectives while caring for them shaped their productive engagement in these practices. The relationship between pets and humans facilitated an ecological and relational approach to science learning.
Contribution: Our findings suggest that relational practices of caring and perspective-taking coexist with scientific practices and enrich scientific inquiry.

Keywords: science practices, perspective-taking, care, natureculture

Introduction

We have a long way to go in realizing what science studies and learning sciences research have indicated are ideal enactments of engaging learners in responsible, ethical scientific practices in ecosystems. We are haunted by the ghosts of discredited—and dangerous—notions of scientists as objective and distanced white men in white coats serving the colonial project of exploiting and using up natural resources. Further, calls to be in more harmonious relations with nature are frequently based on notions of humans and human culture as separate from nature, and getting "back to nature" as involving leaving contemporary technological tools behind. In contrast, we join the call for emotional and cognitive engagement with "significant others" (Haraway, 2003;

see also Bang & Marin, 2015) in our ecosystems, in relations of mutual responsibility, using technologies to mediate worlds inaccessible to us, and bridging nature and culture.
In this paper, we share a conceptualization of practice-based science education that synthesizes ideas about "naturecultures" where humans have intimate, caring, reciprocal relationships with agentic others in ecological systems, while using contemporary learning technologies. A key aspect of our aim in this synthesis is exploring and clarifying how relational practices such as caring and perspective-taking can both coexist with and enhance scientific and engineering practices (National Research Council, 2012) such as questioning, planning and carrying out investigations, and constructing explanations and designing solutions. We examine the potential of this synthesis for reconfiguring science education through an analysis of a workshop for teenaged humans and their canine and feline animal companions. In this workshop, the humans used Augmented Reality (AR) technologies that assisted them in inquiring into complex phenomena such as pets' sensory experiences in the homes they share with humans.

In the sections that follow, we first review the literature which informs our synthesis, and then describe the particular conceptual framework we use in this study. Then we describe the context and methods of our study of human teens and their animal companions in a virtual summer camp, and present findings from our analysis of relational and scientific practices. Finally, we discuss the significance and implications of this work.

Informing Literature

The literature which informs our initiative is wide-ranging. It includes (a) science studies that describe how we exist in a multispecies network of life, including at home with our animal companions (b) descriptions of how humans learn and relate within networks, (c) literature conceptualizing science education as a practice-based endeavor, and (d) studies of how technologies can facilitate learning and relating within networks. We unpack each of these in turn.

Naturecultures: Multispecies Networked Coexistence

"Naturecultures" (Haraway, 2003; Fuentes, 2010) refer to combinations of biological, technological, and other entities in hybridized, entangled, and networked relations through material and cultural systems of meaning and exchange. The notion of naturecultures highlights the inseparability of nature and human activity in relationships, constituted by complex transactions within a network of co-constructed relations.

Networks of relations in ecosystems are central to contemporary biological research. David George Haskell observes how different constituents of ecologies are interdependent: living organisms are parts of networked living systems that are inseparable. "Life is embodied network" (Haskell, 2017, p. x). Further, Haskell notes:

> Because life is network, there is no "nature" or "environment," separate and apart from humans. We are part of the community of life, composed of relationships with "others," so the human/nature duality that lives near the heart of many philosophies is, from a biological perspective, illusory. (Haskell, 2017, p. x)

Kimmerer (2015) contrasts the Western view of an ecosystem—with humans at the top and plants and animals inhabiting lower hierarchies of beings—with the Indigenous view that understands plants and humans as cohabitants of an ecosystem, linked in a co-evolutionary circle

while shaping each other (p. 124). Plants, as carbon fixers on earth, feed other creatures while ensuring their own evolutionary survival, making humans dependent on them.

Beyond the biological sciences, post-humanist new materialism further draws attention to multispecies networked coexistence. As Dolphijn & Van der Tuin put it, "the entanglement of matter and meaning calls into question this set of dualisms that places nature on one side and culture on the other" (2012, p. 94). Kimmerer (2015) sees standard scientific tools and methods as troubling when they reduce plants solely to study objects. Actor Network Theory (Latour, 1998) considers the relational, networked system of human and non-human biological organisms and material technologies (i.e., "technoscience") as the object of study. Together, these scientific and philosophical orientations resist the perception of the world taken to be separate from the perceiver, to be examined, analyzed, and understood solely through cold cognition. Across these views, entanglement is the recognition of the mutual shaping of all entities in natureculture.

Relating within multispecies networks

Barbara McClintock won the Nobel Prize in Physiology or Medicine for the discovery of mobile genetic elements in maize. McClintock's approach to scientific work is famous for its attention to the individual and minute individual differences. In a move away from cold cognition, she emphasized relations in her approach to science, stressing the need to develop "a feeling for the organism" that favors the ability to "see one kernel that is different, and make that understandable" rather than "call it an exception, an aberrant, a contaminant" (Keller, 1984, p. xiii). McClintock further explained,

> I start with the seedling, and I don't want to leave it. I don't feel I really know the story if I don't watch the plant all the way along. So I know every plant in the field. I know them intimately, and I find it a great pleasure to know them (McClintock, as quoted in Keller, 1984).

McClintock's methods facilitated her understanding of the hidden world of maize chromosomes, how they were sensitive to environmental changes, and how these resulted in visible phenotypic changes in maize kernels. Tools helped her notice and study chromosomal changes, but her close relationship and commitment to the plants she grew helped her attune to the plants within a network where she was the knower and the maize plants, the known. Her relational approach to studying maize plants avoided imposing answers and imagining best fits to explain phenomena; instead, she learned to be with the maize in a sense of kinship, co-becoming (Roy, 2018, p. 53). As a result, she developed a sensitivity to communicate and be communicated with by her non-human collaborators by venturing beyond benevolent affection towards the plants she grew. The plants were more than objects at her disposal (Roy, 2018, p. 86); she sensed an ethical responsibility and commitment toward them. Recent work in multispecies flourishing indicates that entities are connected naturally, culturally, economically, and politically within networks (Fuentes, 2010); McClintock's experience exemplified what it means to relate within multispecies networks.

The existence and emergence of multispecies networks, however, are notoriously difficult to see and understand as people are not limited to human ways and logics. Not all entities within networks (for example, microbes) are accessible to human perception and cognition, and hence, relatable to humans. However, our human ways need not be the only ways of thinking that are available to us. There is something about our everyday engagements with other kinds of creatures that can open new kinds of possibilities for relating and understanding (Kohn, 2013).

Pets, as significant others in our lives, present to us the opportunity to study relating within networks. Our animal companions are not "surrogates for theory; they are not here just to think with. They are here to live with" (Haraway, 2003, p. 5). As creatures we are "in relation with" in the ecology of the human home, pets' perception of the world around them makes networks accessible to humans. Thinking of human-pet relationships as co-constitutive; "none of the partners pre-exist the relating, and the relating is never done once and for all" (p. 12), we understand relationality as follows. First, that entities exist in relation to one another; second, there are ways entities relate to one another; and third, the relations and how they relate—how entities "become with" one another—evolve over time (Kohn, 2013). We next detail what relational learning entails for science education.

Toward a relational science education

Although the work of scientists and engineers is a creative and human endeavor (National Research Council, 2012, p. 42), many youth and adults do not see it that way. For example, American youth and adults have been found to have distinct stereotypes of science and scientists, often believing that they are socially distant, dangerous, workaholics, peculiar, irreligious, and missing fun in their lives (Carter, 2006; Grover et al., 2014; Losh, 2010; Mason et al., 1991; Martin, 2004;). These stereotypes of scientists indicate that many youth and adults perceive scientific work as purely academic and devoid of relational attributes such as care, feelings of empathy, and joy.

Dominant Western scientific practice values a positivist, objective view of the world, requiring learners to treat and study nature in isolation, conducting controlled studies while maintaining "value neutrality" (Harding, 2015). Scholars from a variety of traditions have argued that this view of scientific practice is far from complete or even accurate, and have documented scientific methodologies that rely on the knower, the science practitioner in relation to the mutual, structural, and social interconnectedness of life where agency of all elements and multiple ways of knowing are key (e.g., Bang et al., 2012; Boyd, 1980; Brayboy et al., 2008; Cajete, 2000; Latour, 1987; Pickering, 1995). Together, these methods favor two interconnected views. First, as noted above, nature and culture are inseparable (Haraway, 2003; Fuentes, 2010); an integrated, multispecies, contextual knowledge of naturalcultural relations is instrumental to creating a thriving multispecies coexistence (Kimmerer, 2015). Second, methods, ways of knowing, and skills and tools exist that make these relations visible. Relational science education encourages a more complete account of the world that the learner meticulously and caringly constitutes as a practitioner. The learner, in this view, is situated in the cultural, material, social, geographic, and semiotic planes (Brown et al., 1989; Greeno, 1998; Nasir et al., 2020; Suchman, 1998) as well as epistemological, ontological, ethical, and political planes (Booker & Esmonde, 2016; Haraway, 1988; Keller, 1984; Nasir et al., 2020). Their epistemology is a function of their existence across these planes rather than just one. To this end, natureculture constructs benefit science education by helping learners to recognize the natural world as a complex and interconnected system, fostering an understanding of environmental issues (McGowan & Bell, 2012), developing a sense of reciprocity with the environment and the role one plays in it (Marin & Bang, 2018), and encouraging critical thinking skills by challenging assumptions about nature and human-environment interactions (Ogden et al., 2013).

Informed in part by the above, recent science education reform proposes a way forward—a three-dimensional view of scientific inquiry, one that supports learners' engagement in practices, disciplinary knowledge, and crosscutting concepts while finding out about the natural

and man-made world (National Research Council, 2012). Often, questions about how to engage learners meaningfully and authentically in such inquiry become salient. Inquiry needs to emerge from authentic activity as learners engage in practices to make sense of a problem or a phenomenon, using tools, models, etc. that are age-appropriate and suitable for the specific purpose. Therefore, learning environments need to be designed and implemented to support learners' "figuring something out" through science and engineering practices (Berland & Hammer, 2012). We attend to authenticity and meaningful inquiry in two ways. First, we chose a context that is familiar to participants – pets. Pets are much-loved family members in many cultures. 70% of households in the United States own pets, with 69 million households owning dogs and 45.3 million households owning cats (Insurance Information Institute, 2019), indicating that this is a familiar context to many learners. Second, owing to the closeness of human and animal companions' relationships, learners are likely to be motivated to inquire into pets' lives and understand the perspectives of animal non-human others that are "minded beings" (Sanders & Arluke, 1993). With the right tools to facilitate their inquiry, it might be possible for learners to authentically figure out pets' lives and shift perceptions of how the material and relational constitute all living beings' experience of naturecultures.

Research on youth's learning with pets

Research on human interaction with animals and animal cognition has a historical trajectory. Moving on from studies of animals' use of specific technological resources such as conditioning chambers (Skinner, 1959), robotic machines (Rossing & Hogewerf, 1997), and domestic tools such as light switches and machines (Mancini, 2017), researchers have begun to prioritize animals' perspectives in the use of tools. Animal-Computer Interaction has developed ways to capture animals' experience with the human-designed world. Through user-centered and participatory design approaches, along with critical animal studies and multispecies ethnography, research has emphasized that animals are agentic actors. The above methodologies, along with studies on dogs' sensory interaction in environments (for example, Horowitz, 2010) and animal participation with humans in the design process (for example, Hirskyj-Douglas et al., 2017), demonstrate what becoming with animals entails. Haraway (2008) described "becoming with companion species" as a way of thinking about the relationships between humans and other animals that emphasize the co-evolution and mutual transformation that occurs in these relationships. Haraway argued that humans and other animals are not separate or distinct entities but rather part of a complex web of relationships in which each species shapes and is shaped by the others, suggesting that we should think of these relationships as ongoing processes of becoming, rather than as asymmetrical (humans find ways to overpower most animals), fixed, and predetermined.

More specifically, research on human youth learning and becoming with animals indicates rewarding outcomes. Despite the possibility of anthropomorphism (Kattman, 2007; Williams et al., 2020; Zohar & Ginossar, 1998), youth-pet relationships have led to general positive outcomes such as youth developing caring attitudes towards and a valuable understanding of ecosystems (Bai & Romanycia, 2012; Russell, 2017), gaining factual knowledge of animals' habitats and nature (Bonus & Mares, 2018; Geerdts et al., 2016), and knowledge of more wild, less domesticated species (McCabe and Nekaris, 2018). Research also shows that youths' close relationships with nature (Bang et al., 2007; Faber Taylor et al., 2022) and relationships with pets and animals at home (Melson, 2001; Prokop et al., 2008; Zimmerman, 2012) and in the local community (Koda, 2013; Shapiro et al., 2017), are rich in the promise of science learning. In addition, closeness with animals teaches youth to be

compassionate individuals actively seeking to care (Borgi & Cirulli, 2016; Logan & Russell, 2015), feel more confident about their abilities (Simeonsdotter Svensson, 2014), and maintain curiosity about other animals (Russell, 2017; Shapiro et al., 2017). Further, strong human-pet relationships help youth develop empathy and understand emotion and complex multispecies interactions within a fluid ecosystem (Russell, 2017) and human and pet coexistence with it. Our work analyzes the possibilities that emerge when teens learn with pets, about pets' senses, through active engagement in the inquiry process, thereby adding to this existing body of research.

The above literature on youth-animal relationships indicates that their lives are entangled in different ways, both in terms of their existence in networked ecosystems, determined by nature and their everyday interactions, shaped by human-made environments, norms, and individual tendencies. Through their interactions, youth and pets mutually shape each other. We begin from the most common entanglement around us—youth and pet companions at home. Although not guaranteed, the nature of the youth-pet entanglement implies the possibility of critical observation and thinking shaped by individual interests and cultural forces such as books, TV shows, social expectations, and the widely accepted ethics of pet care. As pets respond to human ways of living, they transgress the perceived nature-culture divide. We, as humans, are equipped to respond to most of these transgressions in comparison to transgressions of, for example, coyotes or rodents, due to our close and caring relationships with pets. Finally, since most research in science learning in natureculture concerns youth's entanglement with plants, soil, ocean creatures, etc., whose responses to human actions are difficult for humans to register, our conceptualization is in a context where the symbiotic relationship is apparent.

Tools to Facilitate Relating within Networks

Tools can mediate between our sensory abilities and the world that lies beyond by helping us overcome our otherwise biologically-limiting senses relative to specific purposes (Eisenberg, 2017a, 2017b). One way to inquire into naturecultures, especially in the context of pets as companion species, is through extending our senses to animals' sensory abilities. Each creature has its own "umwelt" (von Uexküll, 2001; Yong, 2022)—the world as experienced by a particular creature, a window into sensory experiences. Umwelts are unique and difficult for other species, for example, humans, to imagine. The unique affordances and limitations of an umwelt in one species' life are typically beyond the grasp of others. Technologies that give us access to animal umwelts can help us partially capture what species sense and rely on to coexist in networks. By extension, human awareness of more-than-human umwelts can help us become informed allies in coexistence. We use the phrase "more-than-human," as opposed to "non-human," to emphasize the connections across humans and other species within the natural world (e.g., Bang, 2016; Hecht & Nelson, 2021).

Scholars have recently investigated how technologies such as immersive virtual environments can enhance social perspective taking (Gehlbach et al., 2015; Oh et al., 2016) leading to conflict resolution. Computer-augmented embodied perspective-taking in difficult to understand STEM areas has been shown to encourage a productive "learning stance" (Lindgren, 2012) and to enhance both conceptual learning and engagement (Danish, 2014; Lindgren et al. 2016). In parallel, scholars have found that building relational ties to non-human actors in nature may contribute to environmental and biology education by helping learners listen to nature (Bang & Marin, 2015; McKenzie, 2009). To this end, wearable devices have been found to motivate empathy and understanding of nature. A series of mushroom-foraging tools designed to enhance a human's perspective in relation to multispecies coexistence through engagement,

attunement, and expansion, were found to build more intimate relationships between humans and the environment (Liu et al., 2018). Educators have asked learners to take on the embodied experiences of insects such as bees and animals such as polar bears. Danish (2014), Peppler and colleagues (2010) found that K-12 students enacting a computer-augmented pollination activity embodying the role of bees learned the nuances of individual and aggregate bee behavior. Relatedly, Lyons and colleagues (2012) found that asking people to use wearable polar bear paws as an input device for a simulation of polar bear experience traversing melting polar ice enabled an empathetic understanding of the impact of climate change by offering museum visitors the ability to take up the perspective of the polar bear. This body of research indicates encouraging outcomes of technology-enhanced, relational science learning through perspective taking.

Perspective-taking and care are essential in shaping our understanding of the complexities of animals' lives; as learners see the world from more-than-human points of view, the boundaries between humans and more-than-human can temporarily blur. In such moments of redefinition and reorientation, learners can begin to understand some ways in which human and more-than-human lives are entangled in natureculture. Such understanding is valuable in supporting the coexistence of humans and more-than-human, as well as in scientific research settings, where our actions profoundly impact the lives of animals. To examine the potential of this idea, we analyze a workshop for teenage humans and their canine and feline pets, which utilized Augmented Reality (AR) technologies to understand the pets' sensory experiences in the homes they share with humans. Our analsyis of this workshop demonstrates the potential of integrating caring and perspective-taking practices with scientific and engineering practices, highlighting the importance of developing a more holistic understanding of animals' lives.

Conceptual Framework

Our conceptual framework in this paper is comprised of the relational practices perspective-taking and care, Science and Engineering Practices (SEPs), and human-animal companion coexistence in natureculture.

Relational practices of perspective-taking and care

We focus on two relational practices—perspective-taking and care—as keys to illuminating human-animal companion relationships within natureculture. We conjectured that in adopting pets' perspectives and practicing care toward their pets, learners may appropriate scientific practices in inquiring into their pets' lives. Since natureculture is complex and difficult to understand, the human-pet relationship might motivate learners to persist in inquiry and careful noticing while appreciating the pets' agency. We define the terms as follows.

Perspective-taking is an individual's cognitive, emotional, and motivational capacity to consider the world from other viewpoints (Roan et al., 2009). It is widely accepted that we know of the world from our unique perspective. The ability to adopt perspectives is considered vital to science education in a range of contexts, from agent-based systems (Nemirovsky, 1998; Sengupta et al., 2021; Wilensky & Reisman, 2006) to socioscientific issues (Kahn & Zeidler, 2019; Newton & Zeidler, 2020). However, despite positive learning outcomes of successful perspective-taking and the acceptance that perspective-taking tools are objects of reflection (Nemirovsky, 1998), we know little about perspective-taking within natureculture and its relation to learning. Perspective-taking, as an ability, and AR tools as mediators of perspectives, open up opportunities for learners to explore relations within natureculture. To *care* is to

demonstrate a morally developmental stance meant to attentively rehabilitate another (Held, 2006; Jennings, 2018). To care is to strive to understand a situation from another perspective and value the recipient as a responsive agent (Jennings, 2018). Hence, care is relational; it denotes the recipient's need for care and the carer's assumption of responsibility. Caring for nature is a means of relating affectively and practically to nature (Jax et al., 2018; Buch, 2015) resulting in commonality and reciprocity between humans and non-humans.

Perspective-taking and caring practices can work in tandem. Winther-Lindquist refers to "responsive caring" among humans as instances where actors ask themselves "if I were you – not as I am, but as you are – what would I need/want/desire?" (2021, p. 7). This requires decentering oneself, and considering the perspective of the other. Similarly, since people often view their pets as companions and loved members of the family (Bilger, 2003; Bucks, 1903), in the act of caring responsively for their animal companion, people may seek to understand the perspectives of these "significant others." Nonetheless, just as humans can only partially understand how other humans experience the world, there are limits to how well humans can appreciate and make sense of other species' sensory, cognitive, and emotional experiences (Nagel, 1974).

Science and Engineering Practices

We utilize three science and engineering practices (SEPs) articulated in the *Framework for K-12 Science Education* (National Research Council, 2012) and adopted in the Next Generation Science Standards (NGSS Lead States, 2013): Questioning, Planning and Carrying out Investigations, and Constructing Explanations and Designing Solutions. These three practices can work together as resources for learners' sensemaking, particularly in relation to a phenomenon like the sensory experiences of animal companions. In our workshops with youth described in more detail below, for instance, we asked participants to ask questions about their pets' sensory experiences. Those questions then informed investigations into their pets' vision-related experiences at home. Those investigations enabled the youth to construct explanations and design solutions in the form of new toys or environments for their pets. Finally, those investigations and the shortcomings of the explanations led to more questions.

Agents Acting with Tools and Others in Naturecultures

Desire to understand how pets are experiencing the ecologies they share with humans may motivate people to not only scientifically investigate differences in perception and daily lives, but also shift perceptions of how the material and relational constitute all living beings' experience of naturecultures. To make sense of such phenomena, we rely in this paper on the notion of agents-acting-with-tools-and-others-in-networked-naturecultures. We focus on pets as representatives of more-than-human others in a learner-pet dyad in the ecosystem of human homes. Limiting our focus on the pets as representatives of "others" helps us focus on the relationality within the teen-pet dyad.

Putting the above concepts together, we seek to answer two research questions:

> *1. While studying pets' experiences at home, how do youth engage in the scientific practices of planning and carrying out investigations, constructing explanations and designing solutions, and questioning?*
>
> *2. How do perspective-taking and care inform teens' scientific practices of planning and carrying out investigations, constructing explanations and designing solutions, and questioning?*

Methods

Authors' positionality

Shapiro and colleague Mike Eisenberg formulated the original project concept, and Polman joined the grant proposal team. After Eisenberg had to discontinue participation in the project due to health reasons, Kane joined the team as an investigator. Polman, Kane, and two graduate students (Annie Kelly and Gabriella Johnson)designed the workshop plan. The primary facilitators of the workshop with the teens and the pets were the graduate students, assisted by Polman and Kane; Shapiro provided input and guidance. After the workshop was conducted, Parekh joined the project and analyzed the data. In addition to our roles in the workshop and data analysis, each of the authors and other team members have close relationships with pets at home. Shapiro and Polman each enjoy the companionship of two dogs. Kane's family includes three cats, each with a distinct persona, and Parekh's family includes a dog. All team members seek to ensure that their pet companions enjoy considerable time and attention from humans and have routines and spaces at home dedicated to their wellbeing. Our team has expertise in learning sciences (Parekh, Polman, and Shapiro), computer science and HCI (Kane and Shapiro), and science education (Parekh and Polman). We have sought to educate ourselves in recent years about dog and cat cognition, naturecultures, ecological relations, and indigenous ways of knowing and being; we aim to counter the relations of dominance and exploitation that *Homo sapiens*—especially in Western European cultures—has historically taken up toward other species and the planet as well as towards marginalized communities within our species.

Study design

We designed the study with the intent to support youth engaging with and observing pets at home. Since pets' experiences are distinct and interspecies communication is challenging, we offered youth a glimpse into pets' visual worlds using AR tools to adopt the pets' perspective. Based on this goal, and the importance of relational science education with naturecultures articulated above, we designed a two-week-long virtual workshop for youth and pets at home.

We designed workshop activities based on a previous study (Kelly et al., 2021; Parekh et al., 2022) of perspective-taking and empathy in families' inquiry into their pets' lives, with a particular focus on building out support for teens' perspective-taking and care along with scientific inquiry. The events at the workshop were spread over two weeks. In Week 1, participants used AR tools (see below) to support perspective-taking and scientific inquiry into pets' experiences at home. The basis for these activities was connecting participants' caring motives to understanding the world better from their pets' points of view. We conjectured that this perspective-taking and the existing care between the teens and the pets would lead to insights and goals to drive participants' Week 2 experience design projects. We describe recruitment and the workshop plan below.

Recruitment

We recruited middle school and high school-aged adolescents through a university-run STEM workshop participant mailing list and through social media. Youth on the mailing list had previously engaged in STEM summer programs. The criteria for participation were as follows: aged between 13-18 years, at least one dog or cat at home, and access to the internet and a computer for the two weeks. 13 teens joined the program, along with their 9 dog and 5 cat companions.

Workshop Design

Facing the challenge of the COVID-19 pandemic in summer 2020, we designed a two-week virtual camp with a mixture of synchronous and asynchronous at-home activities that situated science and engineering practices and design work within teens' homes, which they shared with their pets (Kelly et al., 2021; Parekh et al., 2022). Each participant individually maintained a document we referred to as their "Pet Blog," which contained all their documentation for the daily at-home activities, project updates, images, notes, and blog posts. To support collaboration between participants, we used shared Google documents and conducted smaller group discussions in Zoom breakout rooms. Each participant used their own electronic devices and received a box of materials (pet toys, treats, and craft materials) from us to support their individual project work. On each day of the camp, we met with participants as a group for approximately an hour each morning over Zoom to lead collaborative sessions and share the previous day's at-home work. Towards the end of each meeting, we explained the at-home activity for the day, which participants completed on their own time with the option to reach out to facilitators for assistance. After the camp, we conducted semi-structured interviews (details can be found in the following section) with participants to learn more about their camp experiences.

We used a suite of three tools to support participants' understanding of their pets' lives during the workshop. **First**, we developed AR filters called DoggyVision and KittyVision that approximated the differences between humans and canine and feline vision, respectively. We included the three factors that distinguish dog, cat, and human vision: red-green colorblindness, diminished visual acuity, and reduced brightness discrimination (Miller & Murphy, 1995) in the design of this filter. This filter mediated the pets' reality by manipulating the humans' perception, specifically, by subtracting information from the human's visual perception. **Second**, using behavior-tracking methods from the animal sciences (Lehner, 1992), we developed a table template for participants to track the various observable traits and behaviors of the pets, and make claims about the pet's emotional and mental state. **Third**, inspired by research on design methods to represent dogs as stakeholders in the designs of interfaces (Hirskyj-Douglas et al 2017), we provided participants with a template for creating design personas, "pet-sonas," for their pets. These pet-sona templates encouraged participants to develop a model of their pet's personality and collect information on how their pet responded to events at home and interacted with the projects created by the participants. The AR filters, along with the behavior-tracking tool, helped participants correlate pets' perceptions with behavior. Since pets cannot communicate with words, humans and pets learn to communicate through interactions and behaviors (Haraway, 2003).

In the camp's first week, participants shared details about their pets, their interactions with the pets at home throughout their lives, and their general feelings about their pets. This formed the basis of what we know of the participants' knowledge of pets, and specifically, their pets' behavior. Following these discussions, participants investigated pets' senses and related behaviors using the filters and structured reflection tools (See Appendix). Following semi-structured explorations using the filters involving the participants and pets, we supported participants in perspective-taking through structured, information-seeking, and reflective discussions. For example, on the first day of the workshop, we included a scavenger hunt in and around the home with the pets to support teens to adopt their pets' visual perspectives. The teens

photographed the pets' surroundings at each location and reflected on how the pets' visual perceptions differed from theirs. Then, based on these reflections and their understandings of their pets' nature, participants framed overarching, investigable questions, and planned investigations to understand aspects of their pets' vision. The facilitators contributed to the workshop by introducing each day's agenda to the participants, describing the tools and its expected use, and responding to questions asked during the synchronous sessions and through the participants' pet blogs (described later). Examples of questions and wonderings from participants in these sessions include the following: "Is my dog the only dog that likes to watch TV?" "I wondered what might happen if I used a different food bowl in this investigation." "I found that only one of my dogs showed any interest in this investigation and wondered why it was so."

Participants planned and implemented design projects in the second week of camp to enrich some aspects of their pets' lives. Based on filter-tool-enabled observations, investigation outcomes, and their understanding of pets' sensory experiences at home in a range of everyday activities such as play or mealtime, participants planned and carried out a design project. Finally, all participants prepared and presented a video presentation describing their final project, motives, the design process, and lessons learned at the workshop. After the workshop, facilitators remotely interviewed ten participants following a set of predetermined questions in three categories: overall experiences of the workshop, learning experiences, and science identity. For this analysis, we analyzed participants' responses to the first two sets of questions: overall experiences of the program (participants' feedback on the workshop design, their experience of findings out about their pets' lives, working with the pets, the nature of support received, if any, from family members), and learning experiences (examples of things learned about pets, ways in which participants were able to use science to find out about the pets, participants' rationale for the projects they worked on, their experience of designing projects for and with the pets). Each interview lasted approximately thirty minutes.

Data Collection

We recorded all synchronous virtual workshop sessions and breakout groups. We also recorded all post-workshop participant interviews and collected participant-generated Pet Blogs and video recordings of their presentations of the final experience design projects. Later, we transcribed all session recordings and interviews.

Data Analysis

Two of the thirteen youth did not complete the workshop and two others did not participate at a level sufficient for case analysis. We analyzed the remaining nine cases, but in this paper, we share our analysis of three of the human-pet participant cases at the workshop (see Tables 1 and 2 below for information). We chose these participants solely to support the depth of description and analysis and for limitations of space. We refer to participants collectively as teens, youth, and participants. Teens with multiple pets chose one of their pets to be their main companion for the camp. All names of humans and pets are pseudonyms.

We present our findings as a case study (Stake, 1995), to capture the complexity of the relationships within the home ecology of individual participants and the group of participants at the workshop. Within the case study, our unit of analysis (Grünbaum, 2007) is each individual human-pet relationship within the ecology of their home. We used multiple data sources (transcripts of the synchronous workshop sessions, pet blogs created by participants, and

Table 1

Summary of investigations conducted by participants

Participants (age)	• **Driving Questions** • **Investigation Plan**	**Investigation outcomes**	**Interpretation**
Violet (human female, fourteen) and Billie (dog, one-and-half) Figure 1.1a, b	What colors does my dog prefer? What colored toys does my dog prefer? a. Violet initially arranged colored construction paper in the order of the colors of a rainbow. She asked Billie to choose a color by pointing to the setup and saying, "Go, Billie!" but the dog showed no interest. She then placed treats on top of colored paper. b. Later, Violet wondered if Billie's choice was motivated by the treats, and hence, she arranged toys in the colors of the rainbow and asked Billie to choose one. c. Next, Violet offered a choice of balls only to Billie. Violet knew that the yellow balls would appear very pale to Billie.	a. Billie chose the treats on the blue shades on all three trials of the investigation. b. Billie chose a blue toy. c. Billie chose a pale-looking yellow tennis ball.	Violet assumed that Billie was going straight to the treats, and hence, he was choosing a treat and not the color, which is what Violet wanted to find out. When Billie repeatedly chose blue colored paper and a blue toy which was the dog's favorite, Violet offered her some tennis balls to choose from. When Billie chose a pale-looking yellow tennis ball, Violet wondered if she chose the ball because it was a favorite of the family's other dog and smelled of the humans as well.

Evee (human female, seventeen) and Saskia (cat, thirteen) Figure 1.2	Does the color of the paper on which food/treats is presented have an impact on which treat Saskia goes to first? The color of the paper on which food/treats are presented impacts which treat Saskia goes to first. Saskia will most likely go for the treat on the yellow or white paper first since the contrast between the treat, and the paper is the greatest. Evee placed one of Saskia's favorite treats onto eight different colors of construction paper in a line. Evee then placed Saskia in a neutral spot and asked her to “Go.“ She used KittyVision to see how the treat looked on the different colors to guess which treat the cat would eat first. Evee conducted three trials of the investigation.	Saskia went to the yellow cutout first and ate the treats on the cutouts on the first row. Saskia did not choose any of the treats on the bottom row. Saskia never chose treats from the black and white cutouts.	Evee concluded that yellow was Saskia’s favorite color, but wanted to find out why. Later, Evee concluded that Saskia was perhaps following Evee’s hand signals and then sniffing for treats nearby. However, Evee’s question is unanswered because the two rows were organized in an array, and Saskia should have been able to smell the treats on the bottom row as well.

Isabel (human female, sixteen) and Leela (cat, seven) Figure 1.3a, b	Do cats prefer food bowls that have colors that are visible to them (such as blue and yellow), or do they prefer bowls in other colors? Does the color of the bowl have any effect on cats? Isabel wanted to find out if her cat, Leela, preferred a particular color of food bowl because Leela had a habit of eating the family's other cat, Nigella's, food. Isabel offered food in a yellow and a blue food bowl to each of the cats independently.	Both cats chose the yellow bowl first and ate the food in it. Isabel viewed the food and the bowl through KittyVision and found that the cat food was more easily visible to cats in the yellow bowl.	Isabel concluded that both cats liked the yellow, could see the food in the yellow bowl, and wanted to eat the food in the yellow bowl compared to the food in the blue bowl. Since Isabel needed to change Leela's behavior, not Nigella's, she changed Leela's food bowl to the yellow one.

Table 2

Summary of experience design projects created by participants

Participants	**Design Objective**	**Results**	**Interpretation**
Violet (fourteen) and Billie (one-and-half) Figure 2.1a, b, c	**Multi-Use Toy (MUT)** Billie is likely to play with a multi-use toy for much longer than a single-use toy. A multi-use toy would replace at least five different categories of toys and still keep Billie entertained and engaged at home.	Billie plays with the toy, uses all its features, and tries to retrieve the toy when Violet takes it away.	Violet interprets Billie's energetic play as successful design of an energetic play experience.
Evee (seventeen) and Saskia (thirteen) Figure 2.2a, b	**Cat House** Saskia loves being in the yard, but will lose her favorite spot soon. A cat house placed in the yard can be her new favorite spot.	Saskia refuses to enter the cat house even after several changes that Evee made to the design.	Aware of Saskia's fear of enclosed spaces, Evee wants to reintroduce the cat house to Saskia at a later date.
Isabel (sixteen) and Leela (seven) Figure 2.3a, b, c	**Catio** Leela loves being outdoors, but we need to supervise her. A catio would serve as a protected outdoor space, and the cat would enjoy spending time here.	Leela enters the catio and spends time inside it.	Isabel sees Leela's readiness to explore the catio as a sign of a successful design of a safe outdoor experience.

transcripts of post-workshop interviews) to fully develop and understand the case as it was shaped by context and workshop activities. In parallel to these, we used the recorded synchronous session videos to clarify details of the participants' descriptions of their work. This approach is suitable to explore a real-life, contemporary bounded system over time through detailed, in-depth data collection involving multiple sources of information (Creswell, 2013, p. 97). We emphasize the commonalities and differences in agents-acting-with-tools-and-others-in-networked-naturecultures. Our approach to data analysis is interpretive and social constructivist (Merriam, 2009).

We chose three—Planning and Carrying out Investigations, Constructing Explanations and Designing Solutions, and Questioning—of the eight science and engineering practices (SEPs; National Research Council, 2012; NGSS Lead States, 2013) for the following reasons. First, together, these three SEPs serve as a resource for understanding pets' vision in natural and designed settings. For example, we asked participants to design and investigate the pets' vision experience and related behavior at home, which aligns with SEP 3: Planning and Carrying out Investigations. Once participants conducted the investigations and designed experiences for pets and observed pet behavior, they needed to interpret pet behavior scientifically (SEP 6: Constructing Explanations and Designing Solutions) and ask questions about their pets' sensory experiences, inquire into their investigations and projects, and reflect on the progression of their inquiry (SEP 1: Questioning). Because of the nature of the workshop engagements, participants also naturally engaged in SEP 4: Analyzing and Interpreting Data, SEP 7: Engaging in Arguing from Evidence inquiry, and SEP8: Obtaining, Evaluating, and Communicating Information; we do not include analyses of these SEPs for the sake of simplicity and depth of our analytic scheme and findings.

We began our analysis by compiling each participant's blog and interview transcripts in one document. After collecting these for each of the nine participants, we coded the transcripts and blogs line-by-line using Dedoose. In the first round of analysis, we coded the documents for the three Science and Engineering Practices (SEPs), and the two relational practices of perspective-taking (Connecting dots of information; Behaving like someone else; Stepping outside of current frames of reference) and care (Attentive companionship; Attentive commitment; Deep relationship; Subject rather than object). We distinguished between two kinds of perspective-taking—first, *perspective checking* based on filter-use, and second, *perspective taking* following working closely with the pets on the investigations and design projects. Next, we identified how the two relational practices informed the SEPs in sections where these codes overlapped. Some observations are as follows. Participants were excited to find out that a pet saw things a certain way, but wanted to be sure that their understanding of the pet's perspective was accurate, delved deeper into the investigation. At other times, participants inquired into why their pet companions had affinities for certain things. For instance, they might long have noted that their pets liked toys or treats, but they might ask what particular attributes of toys and treats appealed to the pets. Further, while conducting their inquiries into the pets' behavior, participants were mindful of their pets as agentic beings who, based on their likes and dislikes, might not respond to their investigation. This way, we identified the themes of caring investigations, attentive interpretation, and subject-rather-than-object. In the second round of analysis, we sought to identify the existence and quality of relationships in natureculture that shape practices and skills, and how. We coded the documents for pet-human, pet-pet, pet-artifact, pet-other

animals, and pet-human-other human relationships in the participants' descriptions of their investigations and designs. We identified two themes: first, the wish to improve pets' lives (solving problems that the pet likely encounters at home) and second, to prevent possible bad experiences (protecting pets from other, "outsider" humans and animals, and avoiding dangers posed by natural and manufactured elements). Overall, as we analyzed these data, we noted the following: (a) the participants' interpretations of their pets' behavior; (b) their understanding of the events in the ecology of the home that elicit these responses; (c) how participants' understanding of events and processes contributed to the human-pet relationship.

Findings

In this section, we first detail the temporal unfolding of the participant's inquiry, paying attention to the pets' responses to human actions, how the teens interpret the pets' responses, and how this process contributes to humans' understanding of the phenomenon of vision in the context of life at home. Then, we elaborate on the moments of confusion and dilemmas that the teens experienced in their role as companions exploring the pets' experience and further examine the change in the teens' scientific inquiry over the two weeks duration of the workshop. Finally, we summarize each section of our findings separately before elaborating the contribution of the teens' positionality to the inquiry.

Overall, we argue that the practice of inquiry informed by perspective-taking and care positions teen participants as learners who are aware of positionality and actions within an ecosystem. In this role, learners are adept at relating within natureculture. In narrating our findings, we illustrate that perspective-taking and care related to the participants' practice of the three SEPs, and how their inquiry positioned learners within naturecultures. After presenting three participant cases, we synthesize our findings with respect to the relevance of perspective-taking and care in participants' practices. We have summarized all investigations in Table 1 and Figure 1 and all experience design projects in Table 2 and Figure 2.

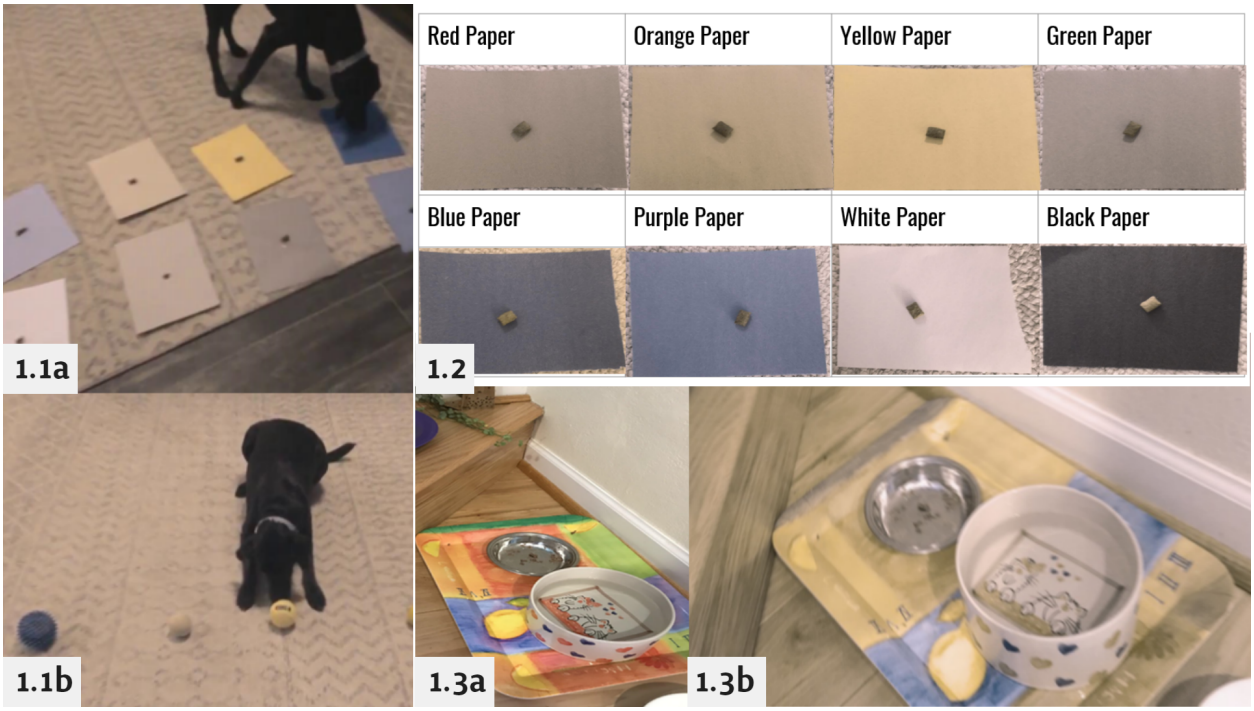
[Insert Table 1, Figure 1, Table 2, and Figure 2 about here]

Case 1: Violet and Billie

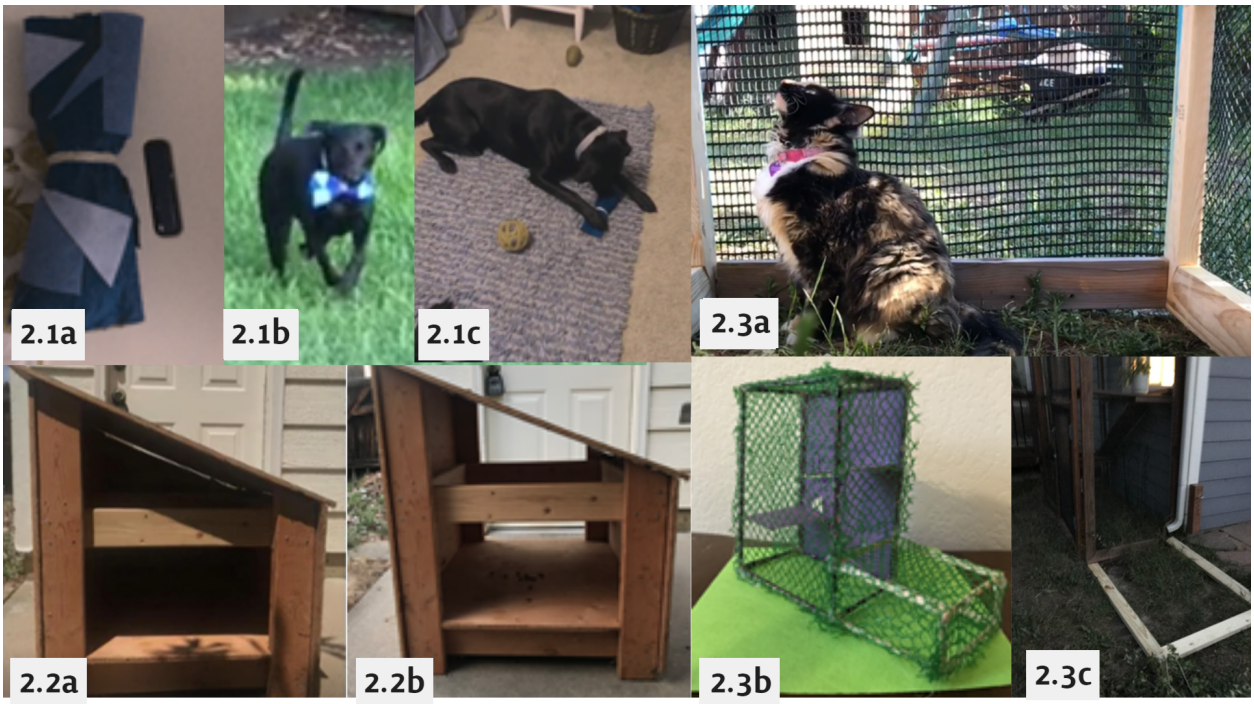
What is Billie's favorite color?

Violet liked colors and actively sought colorful objects for herself and toys in many colors for Billie. Upon finding out, through the use of the AR filter, that Billie could not distinguish many colors, Violet wanted to find out if Billie, from among those colors that dogs could see, had a favorite color and if color affected Billie's choice of toys. Violet planned a simple investigation—she laid out colored paper cutouts in the colors of a rainbow and asked Billie to pick one by saying, "Go, Billie!" When Billie looked confused and did not follow Violet's instructions, she placed dog treats underneath the paper, hoping that the treats would motivate Billie to participate in the investigation. Billie, however, refused to look for the treats underneath the paper, prompting Violet to arrange the treats on top of the paper so Billie could see the treats (Figure 1.1a, b). Using the filter, she checked to see if the treats would indeed be discernable to Billie against the background of the paper. This modification of Violet's original investigation worked, and Billie ate the treats off the sheets of brightly colored paper. Violet explored alternative explanations, saying she "continued to test with the construction paper with treats multiple times switching up the colors to see if she was only going to certain colors because they were close." Violet knew from the DoggyVision filter that shades of blue appear bright in comparison to treats, and Billie chose the treat off the blue shades all three times.

Figure 1. *Images of the investigations captured by teens.* (1.1a, b) Violet's color choice investigation using colored paper and toys; (1.2) Evee organized treats on colored construction paper cutouts in two rows in her treat contrast investigation; (1.3a, b) Isabel's food bowl visibility check. All images other than 1.3a were captured using with Doggy or KittyVision filters.



Figures 2.1 - 2.3. *Experience design projects created by participants at the workshop.* (2.1) Multi-use toy made by Violet captured by DoggyVision, (2.1b and c) Billie enjoying the toy inside and outside the home, (2.2c was captured by DoggyVision); (2.2) Saskia's cat house made by Evee: the original design, (2.2a) and with the back wall removed (2.2b); (2.3) Catio made by Isabel: (2.3a) Leela exploring the catio, (2.3b) a prototypes of the catio, (2.3c) the catio under construction.



Following this, Billie ate the treats on the other colored paper pieces. Not reaching any reliable conclusion, Violet continued with her investigation into Billie's color preference. Next, Violet arranged toys of different colors in a straight line for Billie to choose, Billie once again chose blue—in this case she went straight to a blue spiked toy. However, this time Billie picked an orange tennis ball as well. Billie's choice of toys made Violet wonder if Billie really liked these colors, i.e. blue and orange, or if she liked balls as toys. The orange ball intrigued Violet because she knew using the filter that orange appeared dull to dogs. Violet wondered if Billie chose the orange ball because the dog liked balls as toys. To confirm the reason for Billie's choice of toys *and* colors, Violet modified the investigation yet again; she offered Billie a selection of just balls. For the first time, Billie chose a tennis ball that too appeared dull through DoggyVision. Violet, however, had reason to believe that something besides color was motivating Billie's choice. She discussed it in one of our meetings as follows:

> Violet: This was the first object that she went to that was dull. But maybe it smells of something.
> Facilitator: It smelled of you, probably.
> Violet: Or of Robbie (the family's other dog).

In response to the driving question of her investigation, Violet concluded, "Billie's probably not that into colors." Rather than having a favorite color, Violet concluded that other factors such as visibility, smell (of treats, the other dog, humans) likely motivated Billie more. To answer her questions, Violet looked for multiple sources of evidence of Billie's choice and modified her hypothesis at every step. Based on her observations, Violet repeated her investigation with

modifications and actively sought alternate explanations for the dog's behavior and the investigations' outcome.

Experience design: A Multi-use toy for Billie.

Billie liked toys in general, and the family had gathered several. Seeing that Billie played with a select few toys, and that the many toys inconvenienced her family, Violet wanted to make one toy to provide Billie the experience of playing with four different toys. She planned to insert a squeaker, some treats, and a long rope into the cavity of a hollow ball. The rope would hang out of either side of the ball, giving Billie the opportunity to play tug with it. This new toy would perform the functions of the four popular dog toy categories – squeak, dispense treats, chew, and tug (Figure 2.1a). Violet, however, had trouble securing the squeaker and the treats in the same cavity without creating a potential choking hazard. Seeing the need for a potential solution to this problem, Violet changed her design plan. She made a pouch from blue felt – the color Billie was "most attracted to," inserted the treats and the squeaker inside the multilayered pouch, and tied a rope to its center. This kept the treat side separate from the squeaker side. This way, she could sew the treat-end of the pouch securely and prevent a choking hazard. Billie spent much time trying to get the treats out, and eventually, she succeeded. She liked squeaking the toy as well. However, Billie's play indicated to Violet that the treats were a bit too snug a fit inside the pouch—Billie had to tear a bit of the felt to get the treats out. Violet assumed that if Billie was able to take the treats out easily, she would like the toy more. Further, Billie began playing with the squeaker only when she could take the treats out. Violet loosened the treat-end of the pouch so that Billie could take the treats out easily. Billie succeeded in retrieving the treats from the pouch and proceeded to play tug and squeaked the toy so much that Violet had to take it away from him. Violet shared that she knew that Billie liked the toy because she played with it longer than usual, refused to share it with the family's other dog, and tried to steal it when Violet took it away. Violet's design was motivated by her wish for Billie to have a good time. She had initially interpreted the snug fit of the treats inside the pouch to be a problem with the toy, but later realized from observing Billie playing with the modified toy that the snug fit might have been a positive attribute. Billie seemed to like the challenge of having to take the treats out and was motivated by it. Billie loved the felt toy soaked with her saliva dissolved with treats.

Violet's progression

Shocked to find out through the use of the DoggyVision filter that dogs could not see certain colors and curious to know how the world appeared to Billie, Violet began her inquiry by trying to find out if her dog Billie had a specific preference for a color. She asked, "Does my dog prefer certain colors and does it impact what toys she likes?" Once she had ensured visibility of the investigations' setup to Billie, she no longer found use for the filter. Instead, Violet continued on her own to understand Billie's perspective. She interpreted not just the outcome of the final modification of the investigation but also the process through which she arrived at the final design and Billie's reaction at each step. Based on her observation that Billie repeatedly chose bright blue objects, Violet refined her plan and her question, asking. "I wonder why Billie keeps choosing this blue toy. It is blue, but it is also his favorite toy, so he could have chosen it." Later, when Billie chose a pale tennis ball, she asked if the dog's choice was motivated by competition rather than preference for a toy. Violet's knowledge of Billie's unique sensory perspective, its behavioral implications, and her wish to make life at home good for Billie helped her interpret Billie's response to the investigation. In her persistence to adopt Billie's perspective and her

understanding of Billie as a responsive agent, Violet demonstrated care and shifted the focus of her question from a favorite color to a preference for a particular kind of color, and later to the color and other attributes of toys. Violet's inquiry thus changed from the general effects of selective color vision on Billie's life to the choices Billie made in her everyday life based on her overall sensory experiences and other relational factors.

Analysis: Violet and Billie. The fact that Billie approached the blue paper from among several others arranged in an array and promptly ate the treat on top, suggested to Violet that Billie liked blue. However, Billie could have chosen the blue paper because it was the most visible color that Violet saw through DoggyVision. It was also possible that Billie liked the treats more than the colors and chose the blue paper purely by chance or because it simply stood out in contrast with the treat. In this case, Billie's choice would indicate a preference for treats rather than for a favorite color. Later, when Billie repeatedly picked the blue spiked toy, Violet, once again, wondered if color was the only motivating factor for Billie. Was it possible that some confounds affected the outcome of the investigation? Was the spiked toy also great to chew? Finally, when Billie picked the dull tennis ball, Violet asked, did Billie really respond to a colored object which was barely visible in DoggyVision, or could it have been something else? For example, the smell of his humans who brought the ball out to Billie? Was it possible that Billie chose the ball because it was the other dog's favorite? After considering all of these possibilities, Violet acknowledged that understanding Billie's preferences would require further observation and investigations in different contexts, such as playtime with various toys and habitual behavior with and without the presence of the family's other dog. The filter tool helped Violet gain perspective into canine vision, but Violet's own care for and commitment to Billie and the need to understand Billie's ecological experiences in the natureculture system of play to inform her toy design helped her persist. In turn, this further helped her understand Billie's perspective better. As a committed companion to her pets, Violet was willing to think further about her understanding of the dogs' experiences and their influences on their behavior. She repeatedly considered Billie's experience from Billie's perspective, rather than hers, and stepped out of the constraints of her human perspective to adopt Billie's frame of reference and re-interpret Billie's response to her prompts.

Case 2: Evee and Saskia

What is Saskia's favorite color?

Evee initially felt bad for her cat, Saskia; using the KittyVision filter to adopt the cat's visual perspective, Evee found out that she herself could see many colors, but Saskia could not. Seeing that Saskia's world appeared dull and gray, Evee wondered if her cat Saskia could distinguish her food and treats against the usual surfaces. Given the limited number of colors Saskia could see, Evee wondered whether identifying a food source at home might be challenging for Saskia. Based on the photos she took with KittyVision, Evee set out to extend her understanding of the cat's perspective in everyday situations and conjectured that Saskia would be able to distinguish her reddish-brown food and treats better against certain color backgrounds and planned an investigation. She cut out small construction paper squares in eight different colors and placed a treat on each (Figure 1.2). She asked Saskia to choose a first-choice two times by pointing to the treats with her finger and asking the cat to "go." Evee was intrigued by her observation — rather than the high-contrast treat-paper combinations visible through the KittyVision filter, Saskia chose the treats from the orange and red cutouts first; the yellow cutout with a treat was her second choice twice. Orange, red, and yellow appeared to be similar warm

colors through KittyVision. After selecting the first treat, Saskia sniffed for the remaining treats nearby and consumed them. Evee had to point to these treats with her finger. To Evee's surprise, Saskia ignored the treat pieces on the white and black paper pieces that stood out the most. Evee explained, "She surprisingly went for the orange paper first. . . It was interesting because like she seemed to only go for like that half of the rainbow. She didn't even look at the white or the black, or the blue and the purple." Evee concluded that something other than the color of the paper and its contrast with the treats was motivating Saskia's choice. She wondered if Saskia followed Evee's finger to locate the treats, followed Evee's finger and then sniffed out the rest of the treats, or if the cat just did not follow instructions well but was unable to reconcile these doubts with Saskia's response to both rounds of the investigation. Evee wondered, "if/how this experiment would work on other cats or dogs."

A cat house for an outdoor cat

Considering her investigation inconclusive and Saskia's choices "difficult to understand," Evee turned her attention to other aspects of Saskia's behavior – her choice of favorite hangout spots at home. Saskia, an indoor-outdoor cat, loved spending hours in the yard underneath a swing set or on a dirt patch. Knowing that Saskia was about to lose this favorite outdoor hangout spot in the yard underneath a swing set due to an impending landscaping project, Evee's care for the cat led her to desire making the cat comfortable in a new location. Evee observed that when Saskia was inside the home, she chose spots on the couch and beds that were covered with soft blankets and throws. Upholstery fabric and bedsheets were apparently not comfortable enough for Saskia. Evee constructed an explanation that Saskia probably liked how blankets, throws, and grass feel to touch. Saskia probably liked the smell and touch of dirt on her paws as well. Evee planned to modify an existing dog house to a cat house (Figure 2.2a, b). She planned to place the cat house in the yard and considered protection from the elements a "best of both world[s] situation."

When Evee presented the cat house to Saskia, the cat refused to be in the enclosure. At first this was surprising and Evee could not explain it, as Evee "didn't expect" Saskia to be uncomfortable in the house. But she remembered based on prior experience that Saskia had a fear of being trapped, which might explain her reaction. Evee made several modifications to the design to entice Saskia – she removed the back of the cat house, she placed treats, placed a fluffy blanket and treats inside it, and finally brought the cat house inside the home. When Saskia still refused to enter the cat house each time, Evee sought to find an explanation for Saskia's response, "It might have been that she doesn't love being picked up. I believe it was also because she did not feel comfortable with the house itself." Seeing that Saskia repeatedly rejected the cat house, Evee wondered if Saskia indeed preferred the grass and the dirt to a sheltered enclosure. She continued to think of ways to get Saskia into the cat house but began to question her understanding of the cat's preferences. She planned to stop the project for the summer and revive it in the fall or winter when the cooler temperatures and a frozen yard might motivate Saskia to move into a cat house with a fluffy blanket. "I might try to introduce her to this house again in the late fall or winter when it starts to get cold and the ground frozen is not an option for her to sleep outside but still be comfortable and warm inside the cat house."

Evee's progression

Evee understood using the filter that Saskia could not distinguish many colors and began feeling sorry for the animal. She had questions about whether Saskia had a favorite color from

among the very few that the cat could see. Having initially relied on the filter to understand Saskia's visual perspective, Evee moved on to investigate the cat's perspective in other aspects of life by observing the cat's behavior in different situations. Evee concluded from her investigation that the cat's response to the treats and colors, her gestures, the smell of treats, and the cat's habits could not be separated. Further, despite her desire to believe that her cat was attracted to some colors, Evee persisted in investigating Saskia's perspective and concluded the cat might not have a favorite color or even understand Evee's directions. Wondering if all cats were "difficult to understand," knowing that cats are agentic beings, and feeling the need to study more cats, Evee changed her line of inquiry. She decided to understand a peculiar aspect of Saskia's behavior – Evee found Saskia's choice of hangout spots intriguing. When Saskia repeatedly refused to get inside the cat house meant to provide a safe outdoor shelter, Evee planned to watch Saskia from a distance over months rather than days, move the cat house to a new location in the yard and the home, and keep reminding herself of the cat's preferences. At the same time, Evee started changing her interpretation and explanations of Saskia's behavior. She wondered if the grass and the dirt in the yard were indeed "cozy, warm spots." While interpreting the cat's behavior, Evee was careful to accept certain responses from Saskia as evidence and not others. Further, she expanded and changed the conditions of her investigations when she found that the existing conditions were unfavorable for Saskia. Finally, observing that Saskia's response could be affected by a number of factors and not necessarily her dislike for the investigation conditions, Evee decided to be patient and keep observing Saskia's behavior in the home's natureculture systems to gain a better understanding of the animal.

Analysis: Evee and Saskia. Although Evee hoped that Saskia would use the cat house someday, she acknowledged the possibility that Saskia might give in to her fear of enclosed spaces and not want to use the cat house at all. Based on this, Evee remained optimistic about understanding Saskia's needs better. In her caring commitment towards Saskia's safety and comfort, Evee was willing to repeatedly rethink her approach to understanding problems and solutions. Throughout the process of investigating the cat's behavior, Evee ensured her understanding of the cat's visual perspective, the cat's behavior in relation to senses, considered her observations using the filter, her knowledge of the cat's behavior, and the cat's response to the specific conditions of the investigations to interpret the outcomes. She used both positive and negative outcomes of the unsuccessful design project in explaining what happened in the investigations. Finally, when faced with challenges, Evee chose to step outside the constraints caused by limited understanding of the complex natureculture situation, pause, and gain a better understanding than draw easy but incorrect conclusions.

Case 3: Isabel, Leela, and Nigella

Why won't Leela eat out of her own food bowl?

Isabel's cats, Leela and Nigella, received the same food, but Leela fussed over her food bowl (Figure 1.3a, b); Leela often ate Nigella's food from her bowl instead of her own food, making it appear that she found Nigella's food more appealing. Leela's preference for Nigella's food was strange to Isabel and caused some concern for Nigella — since she cared for them and felt responsible for their nutritional needs, Isabel wanted both cats to get enough to eat. After using the filter and finding out that cats experience selective color vision, Isabel wondered whether cats prefer food bowls in appealing colors and if it matters to cats if their food and food bowl were visible. Isabel began her investigation by using the KittyVision filter and found out that cats could see blue and yellow clearly, but not green. Isabel planned an investigation—she

offered food in blue and yellow bowls at the same time separately to each cat. She ensured that the cat food was visible against each of the bowls and that the particular shade of yellow of the food bowl appeared bright against the background before beginning her investigations. Isabel found that both Leela and Nigella ate out of the yellow bowl first and then the blue bowl. This indicated to Isabel that the cats preferred one bowl to the other one. Noting that she needed to "use this information to persuade Leela to eat out of her own bowl, and not Nigella's," Isabel planned to offer Leela food in a yellow bowl. Isabel hoped this finding of her investigation would help motivate Leela to eat her own food, rather than Nigella's. Nigella would have to eat from the green bowl, and Isabel figured this would not be a problem because Nigella was not as aggressive at seeking out the other cat's food as Leela was. Since Leela did not prefer the color green, she might not want to eat Nigella's food at all. Although her assumption turned out to be true, Isabella acknowledged that the situation left some questions unanswered. If cats indeed had color preferences, wouldn't Nigella be affected by it as well? Nigella having a preference for Leela's food bowl could complicate matters, but Isabel was glad that this wasn't the case. Isabel summed up her investigation as follows: both cats chose the yellow bowl over the green one, however, the reason motivating their choice was unclear. It could be that the cats responded to some other features of the bowl in addition to the color and how the food appeared in the bowl. It was also possible that Leela was a very competitive cat. Isabel concluded her investigation while maintaining that cats are strange creatures and she would need to conduct further investigations into their behavior. Further, understanding cats' visual perspective using the filter was not enough to understand the nature of the problem.

A catio for Leela

Following the investigation, Isabel turned her attention to other peculiar aspects of Leela's behavior. Isabel felt compelled to explore the complex nature of cats' perspective beyond vision. Leela liked spending hours outdoors, "eating grass and spying on the neighbors." As a caring and alert companion to Leela, Isabel noticed that the cat loved being outside, but unfortunately, Leela often tried to escape. Supervising the cat's outdoor time was the only solution, but the family's schedule made it difficult to supervise Leela in the yard. Isabel had tried walking Leela on a leash, and placed cat towers by the window, but Isabel wanted her cat to have what she liked - "fresh air, spying on neighbors, bask in the sunlight, eat grass. . . the complete outdoor experience, but stay close to us at the same time." Isabel concluded that an outdoor enclosure or "catio" was her only solution. She was ready to employ her considerable woodworking skills to construct a catio for Leela.

Isabel began planning the catio by making sketches, complete with relative dimensions of her house and the yard. Once the measurements and the shape of the catio were to her satisfaction, Isabel created a prototype (Figure 2.3a) of the structure using wooden sticks and popsicle sticks, cardboard, and plastic netting with a tiny cat toy to model Leela. Based on this prototype, Isabel and her father purchased chicken wire and wood panels and constructed the enclosure on the weekend after identifying a suitable location beside the home (Figure 2.3b). Next, she added a small door with hinges for Leela to use. The wooden frame, too, had a few hinges that would make it possible for the family to store the catio in the winter when the weather was too severe for Leela to be outside (Figure 2.3c).

When the cat began using the catio, Isabel noticed two problems. First, the location of the catio made it impossible for the cat to see the family in the yard or spy on the neighbors, something Leela enjoyed. Second, there wasn't enough vertical space for Leela to walk with her

tail upright. Based on these observations, Isabel raised the height of the catio by a couple of inches and moved the catio to a different location. Leela responded by entering the enclosure when no one looked and staying there for a few hours. Isabel shared Leela's response to the catio - “At first, Leela was a little confused, but then she liked it. Look at that smile!”

Isabel’s progression

Isabel began her inquiry by understanding what selective color blindness implied for her cats' lives in general, rather than feeling bad about the animals. Parallel to generally exploring selective color vision and its possible negative effects, Isabel tried to understand the possible advantages of seeing a less colorful world and explain how this could be a productive adaptation for cats. She wondered if cats relied on mechanisms other than color vision to their advantage. She reasoned,

> “Cats cannot see reds and greens, meaning that there is less contrast between certain objects. I think that this may cause cats to rely on other ways to navigate and distinguish objects. They may pay attention to specific shapes, depths, or how objects move.”

Isabel planned to observe one of her two cats to see how the cat perceived objects and how this affected her actions. Isabel asked,

> “Do cats prefer food bowls that have colors that are visible to them (such as blue and yellow), or do they prefer bowls in other colors? Does the color of the bowl have any effect on cats? I wonder if cats have any specific reactions to certain colors when they're eating, and if I could use this information to persuade Leela to eat out of her own bowl, and not Nigella's.”

As Isabel investigated Leela’s behavior and finally changed it, she noticed that there were features of the food bowls that she had ignored, and surmised these could have led to different outcomes. For example, the bowls had different depths and shapes; could these other factors have explained why both cats chose the yellow bowl? That the two colored bowls had different depths had not initially struck Isabel as important. Additionally, Isabel wondered if cats would choose different foods based on color and how they discern the quality of meat in the wild without the ability to discern the color red? Her investigation supported her understanding of the cats’ perspectives beyond the effect of color on food bowl choice. Following the questions and observations, when Isabel designed the catio, she paid attention to the right measurement and how the depth and breadth of the enclosure might constitute a desirable experience for Leela. Overall, Isabel seemed to acknowledge that owing to the unique feline vision and cats as responsive agents, her cat Leela might choose and enjoy a different sensory experience from the humans.

Analysis: Isabel and Leela. Observing early on at the workshop that cats and dogs mostly see the world in shades of blue, yellow, gray, and white, Isabel concluded that colors probably weren't as meaningful in the pets’ world as in the human world. In addition to exploring her surroundings using the KittyVision filter, Isabel read about selective color vision in humans and other mammals. By using multiple sources of evidence, Isabel developed the explanation that selective color vision served mammals well by helping them recognize patterns and contrast. Later, Isabel identified more factors in the natureculture system to consider in future investigations of cats’ perspectives to further improve her understanding of the effects of Leela's vision and feeding behavior - the color of the floor the food bowl was placed on and the presence of Nigella, the other cat. She understood her cat Leela's behavior in relation to what she read and

her close observation of the cat. Isabel's repeated reference to her cats as distinct personas implied an awareness of ecological factors in addition to visual perception that might have affected the outcome of the investigation. Her continued attention to the design of the investigation and Leela's behavior implies that she actively sought to clarify the outcomes as emergent from Leela's choice rather than coincidence. Rather than making uninformed predictions of Leela's behavior in seemingly strange situations, Isabel gathered information about cats' behavior in general to support her knowledge of Leela's behavior at home to re-configure her frame of reference.

Practices informed by perspective-taking and care

Each of the three participants began understanding the pets' perspectives using the filter tools (Figure 3a). To find out about their pets' perspectives and lives, the participants designed investigations, employed suitable techniques such as timing pets' responses, noticing pets' reactions to one variable at a time, and removing the influences of environmental factors (Figure 3b). However, while Violet, Isabel, and Evee could manipulate variables, design investigations, and identify and record the outcomes with relative ease, they found interpreting the outcomes challenging. To analyze their pets' experiences as one consisting of sensory abilities, unique preferences, and personas, the teens needed to assume the pet's perspective in investigation settings such as home. Further, the participants found that although they could interpret some aspects of their pets' behavior as distinct cat and dog species-specific behaviors, while others such as preference for color or a particular toy, their response to the visibility of food, and preference for hangout spots were the particular animals' personal attributes.

Adopting a pet's perspective. Violet, Evee, and Isabel's investigations demonstrate that they employed scientific knowledge, tools, and techniques to understand their pets' sensory experiences in the context of everyday activities such as play, relaxing, and eating. Following the use of the filter tools to adopt pets' visual perspectives, and specifically the selective color vision experienced by cats and dogs, all three participants proceeded to design and plan investigations that helped them extend what they already knew of pets. Their investigations were meticulously designed, carefully implemented, and iterated upon; participants were able to answer several questions about their pets. They used multiple sources of information, reflected on their findings, modified their investigations based on these findings, and grappled with complexity and uncertainty. While the answers to their questions helped them understand their pets better, especially pets' behaviors and preferences, and their sensory experiences, the investigations raised further questions, a hallmark of sound scientific inquiry (Polman, 2000; National Research Council, 2012). In asking these questions and considering possible answers to them, the participants complicated their understanding of their pets' perspectives beyond vision to include other sensory perspectives such as smell and related behavior. All three participants' work indicates an awareness of the pets' reaction to their designs and investigations as the pets' expression of preferences. Their iterative re-design and modified investigations are evidence of the mutual shaping of experiences described as becoming with.

Thus, the filter tools also evidently supported perspective-taking. While planning and carrying out the investigations, the participants gathered information about their pets' perspectives. Then, through their investigations, they connected the information of the pets' vision to their prior knowledge of the pets and observations of how the pets responded to the investigation to draw conclusions.

The filters were both perspective-taking and perspective-checking tools. However, most participants framed questions and designed investigations primarily from the perspective a human would have inside the pets' bodies, rather than the pets' perspectives from within entirely different *umwelts*. For example, Violet and Evee assumed that colors were attractive to pets, because they appreciated colors. They also assumed that the treats would act as motivators, secondary factors affecting their pets' choice as they responded to the colors. Violet and Isabel had two pets each and liked both; they assumed that the pets would have similar feelings for each other. That pets can be competitive and their competing for food and toys to influence the outcome of the investigation surprised them. Evee liked the comforts of home and knew that Saskia liked blankets. She assumed that Saskia would like a cat house, forgetting that the cat did not like small enclosures. That the cat might prefer the dirt and grass in the yard to the cat house was difficult for Evee to fathom. In each of these cases, fully adopting the pet's perspective, considering the effect of colors, treats, toys, and shelter proved to be a challenge. When Violet, Evee, and Isabel did take up the pet's perspective, there were simply no alternate explanations for the animal's behavior. When they thought they reached a conclusion about the pets' experience and related behavior in one situation, they moved to another.

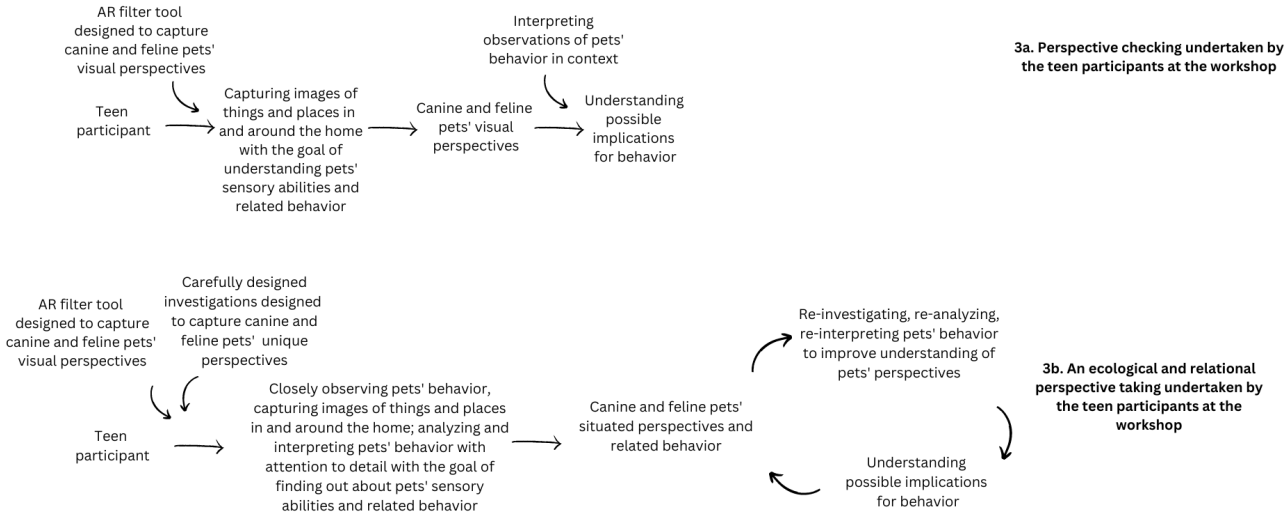
Caring commitment and attention to pets. While inquiring into pets' experiences as careful and attentive companions, the teens observed that pets' experiences with humans are dependent, at least partly, upon what humans understand as general characteristics of cats and dogs, rather than an intentionally and caringly crafted knowledge base for each pet. For example, humans design red-colored pet toys thinking that these would be attractive to the pets when cats and dogs can't distinguish shades of red from shades of green and brown at all. Helping pets live comfortably with humans requires humans to pay attention to the pets' behavior. Caring humans want their pets to have enough to eat and a comfortable, safe place to rest. They try to shield their pets from harm and are mindful of sudden changes to the pet's environment. Understanding a pet's response to events and artifacts at home, however, is not easy. The manner in which pets behave indicates pets' likes, dislikes, and habits, etc. Humans, in turn, respond to pets' behavior further affecting the pets. Therefore, interpreting pets' experiences accurately required attention to context and for humans to step out of their own frame of reference and into the pets' while considering the many factors that affect the pet at home.

While tool-supported perspective taking was a promising starting point, the commitment to a pet companion sustained Violet, Evee, and Isabel's practices. Hence, along with progressions in the participants' perspective-taking, these cases represent each participants' attentive companionship and commitment, and readiness to see the animal as a subject rather than an object. Although a complete understanding of the pet's experiences, especially from the pet's perspective, was yet to be achieved, the attributes of care motivated their continued efforts. Existing research agrees that learners' inquiry can be motivated and driven by more than answering questions, including curiosity, puzzlement, skepticism, and even knowledge-based speculation (Scardamalia & Bereiter, 1992). While learners use questions as "thinking processing skills" (Cuccio-Schirripa & Steiner, 2000), they attempt to reconcile competing theories that shape their inquiry (Watts et al., 1997). To this end, Violet, Evee, and Isabel grappled with the pets' perspectives with some success in their roles as caring humans living with pet companions.

Summary of findings: Understanding pet behavior in the ecosystem of home

Our findings indicate that the study participants were not just humans in charge of pets but rather attentive and caring companions to pets, acknowledging that each pet has a distinct persona. In addition to understanding the pets' experience within the home ecosystem, they readily acknowledged and worked within the well-established norms and expectations of pet care. For example, participants with cats as companions were worried about the cat not spending too much time outdoors for the fear that they might enter the neighbor's yard and disrupt the neighbor's life. Likewise, dog companions were concerned about providing adequate playtime to fully engage the pet, expend energy in young dogs, prevent situations that led to the dogs barking, etc. Figure 3 highlights two key aspects of our findings. First, per our conjecture, all participants were able to adopt pets' visual perspectives and inquire into their lives (Figure 3a). Second, all participants were able to iteratively conduct the inquiry with care and attention to details of the ecosystem and the pets' response to them (Figure 3b).

Figure 3. *Youth's inquiry into pets' senses informed by perspective-taking and care*



Further, the close relationship between human teens and their animal companions provided a context for the investigations and designs serving two purposes. **First,** participants readily understood the investigations and designed experiences as embedded in the ecology of their homes. All participants described elements in their home such as pet toys, soft pet beds, crates, and food bowls as meant for the pet's needs and comfort. Further, participants were mindful of pets' preferences; if humans had preferred spots inside their homes, pets did too. These observations indicate that elements of the home ecosystem had a certain value for pets. Therefore, the events and tools at the workshop helped participants adopt the pets' perspective, and by extension, begin to understand life at home from the pet's unique vantage point. The recognition of the connections between elements within the home ecosystem and beyond (neighbors, social norms, etc.) and their relative importance, especially in relation to the pets' lives, is noteworthy here. Through their attention to the many factors in the ecosystem of home, participants approached a deeper and broader understanding of different attributes of pets' and

humans' existence at home and the pet-human interactions as transcending the nature-culture divide.

Second, understanding the pets' responses in context challenged the teens to acknowledge that the pets were responding to a number of factors, these factors were connected in complex ways, and that some of these factors and connections had little importance to their human existences. These difficult-to-understand ecological interactions were barriers to the teens fully understanding the pets' perspectives and highlight their recognition of the elements within a networked ecosystem as well as the difficulties in perceiving the connectedness. Therefore, pets' experiences as complex phenomena embedded in natureculture were partially accessible to the participants through careful, compassionate, and close observation of pets.

Discussion

We framed learning as reestablishing relationships within naturecultures and argued for the value of a science education infused with perspective-taking and care, embedded in the familiar setting of home and situated in a multispecies networked coexistence. We conjectured that in adopting pets' perspectives and practicing care toward their pets, learners may appropriate scientific practices modified to facilitate inquiring into their pets' lives. We found that learners, mindful of their close relationship with pets and informed by multispecies agency, enacted a relational and scientific practice. We further found that learners acted as members of a complex ecosystem in which they coexisted wifth the pets, and inquirers and observers rather than distant manipulators driven by the sole purpose of gaining knowledge (Bang & Marin, 2015; Hecht & Crowley, 2019). Overall, our findings indicate that the close relationship between human youth and pets indeed served as a rich context for science learning. The AR filter tools mediated a world inaccessible to humans by helping participants gain insights into the visual umwelts experienced by pets and served as invitations into other aspects of pets' sensory experiences and behavior. Following this, the study participants implemented a repertoire of practices to explore their pets' sensory experiences in and around home and, in doing so, explored how the human-animal companion relationship is mutually informing. Therefore, the learners built on their familiarity with and knowledge of their environment. These findings inform research in both the learning sciences and science education. Central to science education are the repertoire of skills and practices we gather across lifespan and spaces as learners (Philip & Azevedo, 2017) and the various processes through which we build our understanding of nature (Warren et al., 2001; Khan & Bowen, 2022; Bang & Marin, 2015; Pugh et al., 2010; Pugh et al., 2019, among others). Core to the learning sciences is the understanding that learning is a way of reestablishing relationships through identifying tensions and iterative observations (for example, Marin & Bang, 2018; Brayboy et al., 2008; Cajete, 2000; Jaber & Hammer, 2016). Overall, our findings indicate an exciting direction for science education for the following reasons.

Perspective-taking as humans

Contextualized perspective-taking runs counter to typical expectations of youth in educational contexts, and hence, we know very little about the barriers to perspective-taking that exist for youth across contexts, especially in contexts that are not entirely digital, and tool mediated. In our study, tool-mediated perspective-taking served as the entryway into science and engineering practices which in turn revealed more details of the pets' perspectives to the participants. Therefore, the filter tools complicated the participants' understanding of the pets' behavior and our understanding of perspective-taking as a tool for learning. Our analysis points

to two different levels of perspective-taking—first, perspective checking comprising a primarily information-gathering endeavor but still with an anthropocentric and egocentric interpretation. Evee talked about Saskia having favorite colors and hangouts, but did not emphasize the importance of the cat's preferences. The second level is a richer level of ecological perspective taking that constitutes reflection and moving away from the human-centric approach yet still fell short of gauging the phenomenon's complete complexity. Violet made repeated changes to her investigations and toy design based on Billie's response but stopped short of acknowledging Billie was motivated by different attributes of a situation. Completely adopting the canine perspective was impossible for her, but since failing to adopt the pets' perspectives consistently produced inconclusive results, Violet and others persevered in continuing their inquiries. This challenge bears similarity to the problem of "presentism" (Wineburg, 1998, p. 338) when novice learners struggle to make sense of historical events informed by radically different spatio-temporal and cultural contexts from their own. Studies in virtual reality-mediated perspective taking (Herrera et al., 2014) indicate similar difficulties, as imagine-self perspective-taking has yielded more positive outcomes than imagine-others perspective-taking in difficult contexts such as homelessness. These challenges prompt us to consider encouraging perspective-taking in difficult contexts and using natureculture constructs. For instance, what might entail adopting the perspective of creatures that, for reasons not immediately accessible to human youth, threaten human existence? At a time when humanity is reeling from the effects of climate change and widespread zoonotic diseases, youth's understanding of natureculture relations must be examined through an understanding of the interactions between, for example, humans and wild carnivores that are losing habitat or between humans and insects that are developing abilities to host different viruses. In addition to the benefit of learning about the unfavorable effects of human activity on these creatures, here, the objective would be to understand the complexities of adopting the perspective of a creature that might cause harm to humans. Augmented and Virtual Reality tools are likely to support perspective-taking to some extent, but the possibilities for application of these newly developed perspectives remains to be seen.

Despite limitations in perspective-taking, in their role as caring companions, our participants were mindful of the needs of their pets as individuals with distinct ways of being and communicating, and this provided valuable insights and resources driving how they carried out science practices. In order to be most effective, they needed to entirely step out of the human frame of reference and dedicate themselves to the pets' perspective. Such a dance between "diving in" and "stepping out" (Ackermann, 1996) of perspectives and positionalities was a complex act indeed. Although rewarding, eye-opening, and informative, switching between in-depth perspectives in complex contexts proved difficult. As a result, a challenge we frequently encountered was in motivating the teens to let go of their personal stance while interpreting pets' experiences. The teens at times misjudged pets' preferences for affordances of toys, enclosures, etc. Not knowing the exact reason(s) for the pets' reactions, they over or under-appreciated the pets' response to attributes such as color and favorite spots. As companions, they expected to have preferences similar to the pets, but the pets' perspectives were only partially accessible to them. Additionally, the assumption that pets would have favorite colors invoked feelings similar to humans having favorite colors, making it difficult for participants to decenter themselves and move toward an appreciation of the pets' experiences as radically different from their own. It is indeed quite difficult for human teens to reach a state of "responsive caring" (Winther-Lindquist, 2021) for pets. Thus, we interpret instances of positioning as caring and attentive humans in a

networked natureculture as a work-in-progress. Further, we are open to the possibility that the intimate, domestic, and inheretly hierarchical nature of the relationship between the teens and their pets might have countered responsive caring in some ways. It is possible that immersing learners in the lives of less familiar species and using tools such as AR and VR, interactive tools, and data visualization might create similar rich learning opportunities. In these settings, the lack of familiarity and proximity with creatures might hinder the learner-led, agentic, persistent inquiry described in this article, but might encourage a different kind of learning. For example, the lack of intimate knowledge of creatures might compel human learners to develop care but also be more open to understanding that less familiar species' umwelts and interactions within networked ecosystem are in fact radically different from humans', which may in turn enable the humans to be better develop understanding of natureculture constructs. These are possibilities worth investigating in future interventions and research studies.

Challenging the complex outcomes of investigations

The fact that most participants in the study were open to alternative interpretations of their findings and pursued further investigations to test those interpretations is a promising sign. While the initial investigations yielded outcomes, the teens recognized the importance of interpreting those outcomes within the broader context and raising new questions for future inquiry. By examining their pets as study subjects, the teens gained insight into the complexities of the ecology of the human home and the role that pets play as agentic companions within that system. The pets' responses and preferences were shaped by the expectations and norms of both humans and animals, adding to the complexity of the situation. The persistence shown by the teens in making sense of this complexity is encouraging, as understanding networked natureculture requires attention to detail, care, and a willingness to accept complexity. This is especially important when considering the context of the study, which focused on human-teen and pet interactions in the setting of an urban, North American home. Given that there are few places on the planet that remain untouched by human action, it is essential to understand the differences that exist within networked naturecultures and the relationships that exist within these systems across different contexts (such as urban neighborhoods, rural farms, forests, etc.). Such an understanding will require attention to detail, persistence, and care. Future studies in this area should also consider the network of meanings embedded in natureculture relations as resources for meaning-making and for value-laden decision-making. By exploring these meanings, learners can move beyond the mere collection of scientific facts and consider the broader implications of their findings for how they want to be and act in the world.

Recognizing the interconnectedness of ecosystems and one's limited perspective can be challenging, but it has significant benefits for learners. Understanding the agency of both human and more-than-human entities and their dynamic relationships within naturecultures requires acknowledging the limitations of human cultural perspectives (Bang & Marin, 2015), which are not value-neutral (Harding, 2015; McGowan & Bell, 2022). This, in turn, highlights the importance of seeing humans as ecological beings and dissolving the boundary between the natural and social worlds to develop ecological consciousness (Taylor, 2020). To nurture such awareness in youth, it is essential to understand their grappling with ecological and relational complexities in their interest-based environments, such as the relationship between human youth and pets at home. Existing frameworks in learning science, such as lines of practice (Azevedo, 2011) and trajectories of identification (Polman & Miller, 2010), can aid in understanding how learners' identities and positioning affect their engagement with ecological and relational complexities.

Additionally, experiences in different settings and with conflicts in natureculture can provide a more comprehensive understanding of these issues. This is also a promising direction for further research.

A new way to learn science: learning to become with the world

Learning science, especially the science of the complex entanglements in natureculture, is vital for learners in the twenty-first century (Kirksey & Helmreich, 2010; Ogden et al., 2013). The research our work is built upon agrees that more is needed than learners thinking of the world as human-centric, where other organisms exist only to fulfill human needs. We need to get beyond "managing" the natural world and solving problems using human ingenuity and tools designed to outsmart nature; it is time for us to learn to be with and become with the complexities in natureculture. However, we find it challenging to see and appreciate the world's complex ecological and relational ties. To this end, our work makes a significant contribution – moving on from valuing learners' understanding of only the human perspective to an awareness of other perspectives and, finally, understanding the nature of other perspectives. In turn, it will further our appreciation of the pedagogical value of relations in the world, moving away from teaching and learning as solely human activities. To bring us closer to this goal, we suggest addressing questions such as: how can we support human learners in adopting a decentered but caring and empathetic understanding of natureculture in context? Rather than understanding the general nature of interactions in natureculture, learners need to understand these interactions as relational and between agentic entities. Further, what constitutes learning within naturecultures while consciously stepping away from a human-centered view? Relatedly, how do situations of crisis, where learners' very existence is threatened, shape learning? Overall, as we progress in understanding learners' relations within natureculture, we need a detailed understanding of what science learning practices might look like in these situations, in addition to how learners shape practices and identities.

Ecologically and relationally-informed science learning as work-in-progress

In conclusion, despite ongoing challenges and ample opportunities for future research such as the ones we detailed above, we see our study as a valuable contribution to making science education inclusive of learners' relational practices, while building on our kinship with more-than-humans. Personally identifying with an investigation and with the research subjects, approaching a scientific investigation with a caring stance, and wanting to adopt the study subject's perspective could offer human learners a pathway to becoming better learners and persons. Consequently, learners could be more motivated and capable of considering the processes, outcomes, and implications of their inquiry, and as Keller and McClintock (1984) described, willing to take the time to look, listen, and feel. However, our work demonstrated that learners need more support as they navigate multiple frames of reference to understand phenomena, indicating that learning science in complex, networked natureculture is a critical process that is yet to be fully understood. We invite others to join us in formulating future studies to examine the learning experiences of youth who experience different ties in natureculture, and hence, appreciate and develop human-more-than-human relations in different ways.

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Appendix

The Structured Observation Tools created by the research team shaped and captured participants' inquiries during the workshop.

Day 1: Scavenger Hunt: The left column in this researcher-created template show the researchers' prompts, while the pictures taken with the DoggyVision filter and right column show Violet's description of everyday objects in and around her home. She noted that dogs could see the color blue very well, explaining why Billie might be most attracted to blue-colored objects.

Item	Notes
My pet's favorite toy 	The dog's favorite toy is an extremely bright shade of blue, which he is probably interested by.
My pet's food and water 	The dog's food and water are both basic silver colors and aren't to entertaining looking.
A colorful item of clothing 	The bandana is bright blue and looks pretty fun, and he really likes it.
Trees or plants (outside) 	The plans outside are really dead looking, despite their vibrant colors because they are green, which DoggyVision/dogs will not see.

Day 5: Behavioral Observation Tool: The gray boxes and blue boxes constiture the researcher-created template here, while Violet's observation of Billie's reaction to events in and around the home appear in the white boxes. She kept a record of Billie's reaction to a car driving by and Billie's body language and actions during the event and tried to understand what these implied.

Friday (Saturday) Report #2 (Afternoon)				
Time & Location of Report:	**7:12, Front Hall**			
What is your pet doing right now? (2-3 sentences)	**Right now The dog is sitting at the front door, staring out of it into the world outside. When a car drives by he will get excited, and sometimes hit the door.**			
The 4 traits you are observing	**Behavior #1 Hands/Paws**	**Behavior #2 Ears**	**Behavior #3Tail**	**Behavior #4 Posture**
What do you observe? (Add pictures to your Pet Blog when possible, to support your claims)	I observed that the dog would start to hit the door when somebody walked by.	I observed that the dog's ears would perk up when he saw something interesting	I observed that the dog's tail was relaxed until something came by the front door.	The dog would sit hunched over, but when he was interested then he would straighten up.
What or who in your pet's environment do you think contributes to this behavior you observe?	This was probably affected by the people going by and the cars in the street.	This was also because of the things outside of the front door.	This was because of the people and cars in the street.	This was another thing because of the things passing in front of the front door.
What does this behavior tell you about your pet's mood or mental state?	This tells me that the dog was excited and wanted to go say hi to the things outside.	This tells me that the dog was happy and interested in what was outside.	This behavior says that the dog was excited to see things outside of the door.	This behavior told me that the dog was excited.
***Why* are you drawing this conclusion from this observation?**	I drew this conclusion because we trained the dog to hit things when he wants them and he probably then wanted to go outside.	I found my conclusion because the dog's ears raise whenever he hears something fun.	This conclusion was found because the dog moves his tail when he sees dogs and he saw dogs when he looked out the door.	I drew my conclusion because the dog likes to sit up straight when he sees people on his walks and he was doing this now.
How would you describe your pet's overall mood based on these observations?	The dog was excited at this time and he would be super excited and happy when something passed by our front door.			