RELATIONAL PROCESSES BETWEEN PEOPLE AND PLACE: UNDERSTANDING ENVIRONMENTAL INTEREST AND IDENTITY THROUGH A LEARNING ECOSYSTEM LENS

by

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Supporting the development of environmental people – 21st century naturalists – is an essential component for addressing the local and global environmental challenges we currently face. My dissertation uses the conceptual frame of learning ecosystems to examine the complex nature of environmental interest and identity development. I explore the benefits of using a learning ecosystem frame as both a theoretical and methodological construct by asking how this opens up ways of thinking about the phenomena of environmental interest and identity development which unfold in dynamic, non-linear ways across time and space.

In this three-paper dissertation, I begin by reviewing the ways that the learning ecosystem framework has been applied in educational literature, coupled with a theoretical proposal for drawing lessons from adaptive biological ecosystem management to improve the use of the framework. I propose two conceptual shifts in learning ecosystem research: 1) the decentering of individuals with a turn towards relational processes as a unit of analysis, and 2) an embrace of place and materiality as a key element of the ecosystem that impacts learning.

I then apply this more robust learning ecosystem framework in two empirical papers that focus on learning ecosystems in Pittsburgh, Pennsylvania. For both empirical papers, I use a collaborative research-practice partnership approach that aims to build trust between researchers and practitioners, uses research to inform action, supports practitioner goals, produces knowledge that informs broader educational improvement goals, and builds capacity for all participants. First,

I examine interest development across the learning ecosystem through the analysis of 18 life-history interviews of adult naturalists. For the final paper, I use an ecosystems lens and ethnographic approaches to develop a nested case study of one informal science program with four cases that describe the relational processes between youth, educators, and nonhuman nature. In the cases, I explore how program infrastructures support the transition of environmental interest into identity for the adolescent participants. Taken together, these three papers offer a closer examination of the application of the learning ecosystem framework to help support environmental interest and identity development.

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1.0 INTRODUCTION

We are in the midst of environmental catastrophe. Humans' outsized and negative influence on global environmental processes is evident from sharp increases in both socio-economic and earth system indicators that began in the middle of the 20th century and have been called the "great acceleration" (e.g., increased water use, surface temperatures, atmospheric carbon dioxide) (Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015). There is much debate about whether or not this marks a new geologic period and, if it is a distinct period, what it should be called; various proposals include the Anthropocene (Waters et al., 2016), Capitalocene (Moore, 2016), Plantationocene (Davis, Moulton, Van Sant, & Williams, 2019), and Chthulucene (Haraway, 2016). Nevertheless, there is little doubt that humans have brought our planet to the brink. Given this, science education needs to be thought of as a tool for not only informing people, but for helping them to develop a curiosity about, and love for, the natural world.

In this dissertation, I explore how learning experiences over time and in different settings, including home, school, and informal learning spaces, such as parks and museums, help people develop their interests and identities, eventually becoming environmental people. The type of environmental person I aim to understand is a *naturalist*. I use this term to indicate my focus on people with tremendous knowledge about and connection with the natural world, but who may have a variety of academic experiences with European-based scientific traditions. They may be professional conservation biologists, or they may be experts on wild edibles who have had little to no academic training. They may be educators or artists, environmental engineers or community activists. They may see themselves as having several of these identities. What unites them as *naturalists* is their attention to observing and understanding natural history through a deep relationship with both human and nonhuman nature, including flora, fauna, land, waters, and air. These are *21st century naturalists* who make local-global connections, engage in civic work, and embrace urban environments as critical spaces to address today's most pressing environmental issues (Hecht, Knutson, & Crowley, 2019; Tewksbury et al., 2014).

Tackling environmental issues, from local water pollution to global climate change, requires scientific literacy that arms people with the tools to help change communities (Van Horne & Bell, 2017). Urban landscapes provide a unique setting to engage learners in local, place-based education that connects them to critical environmental issues, both in their immediate surroundings and in the larger world (Ardoin, Clark, & Kelsey, 2013; Duhn, Malone, & Tesar, 2017; Greenwood, 2017; Smith & Sobel, 2010). The use of these local landscapes allows interest to develop in the places and around the issues that matter to youth (Schindel Dimick, 2016). Connecting science information to students' own experiences (Basu & Barton, 2007) and community values (Bang & Marin, 2015) can help support sustained interest in science.

Becoming a naturalist for the 21st century is a complex venture. To support this interest and identity development, educators need to activate multiple learning settings, from home to school to informal spaces. This breadth of learning places has been called a learning ecology or learning ecosystem (Barron, 2006; Falk & Dierking, 2018; Russell, Knutson, & Crowley, 2013). In this dissertation, I first consider how the learning ecosystem framework has been employed in educational research in a theoretical paper. I propose strengthening the framework by employing lessons from the adaptive management of biological systems.

I then consider how environmental interest and identity are formed across both the temporal and spatial scales of learning ecosystems in two empirical studies. Both projects were completed as part of research-practice partnerships (RPP). Paper 2 was completed as part of a multi-year RPP with the Carnegie Museum of Natural History and Paper 3 was part of a RPP with the Pittsburgh Parks Conservancy. In Paper 2, I use data from life history interviews to explore how adult naturalists came to have their abiding affinity for the natural world through home, school, and informal learning experiences. In Paper 3, I consider the role of informal science programs in a learning ecosystem. I use micro-ethnographic approaches to explore how one informal science program helps youth, who already have a burgeoning interest in the natural world, transition into a deeper individual interest where they begin to envision themselves as environmental people, as having naturalist identities.

1.1 Interest and identity development

Interest and identity development occur as a result of complex processes that are persistent questions in educational research (Ainley & Ainley, 2015; Alexander, Johnson, & Leibham, 2015; Bathgate, Schunn, & Correnti, 2014; Hidi & Renninger, 2006; Krapp, 2002). Designing programmatic experiences that are interest-driven is important for learner engagement which underpins the uptake of domain based concepts (Azevedo, 2013). Interest throughout the course of one's life is central to learning in both in and out-of-school settings, especially for students from nondominant backgrounds that have historically been underrepresented in the sciences, such as Black, Brown, Indigenous and/or poor youth (Bang & Marin, 2015). Interest is also a critical element for developing domain based identity formation, such as thinking of oneself as a science or environmental person (B. D. Jones, Ruff, & Osborne, 2015).

Interest in science has been attributed to both school experiences and self-initiated experiences (Maltese & Tai, 2010). The progression from initial interest that is sparked by external forces to a well-developed and stable, self-initiated interest has been described as a movement from situational to individual interest (Hidi & Renninger, 2006). But how well do we understand how learners move from passing initial interests to persistent individual interests? Understanding the dynamic and complex processes of interest development across different timescales and settings – that is across the learning ecosystem – are underexplored in the literature (Azevedo, 2018).

Informal science programs have been shown to play an important role in the larger learning ecosystem of home, school, and out-of-school settings (National Research Council of the National Academies, 2015), particularly for adolescents who are able to initiate their own learning experiences (Barron, 2006; Crowley, Barron, Knutson, & Martin, 2015). Informal science programs help spark youth interest (Hecht et al., 2019; Pinkard, Erete, Martin, & McKinney de Royston, 2017) and informal science educators can be valuable brokers helping to support youth as they move along pathways to related learning experiences within a learning ecosystem (Ching, Santo, Hoadley, & Peppler, 2016). However, the role of informal programs in learning ecosystems is often merely an onramp for sparking interest development (Hecht et al., 2019); often merely the first step in developing persistent and individual interests that have consequences for identity development (Hidi & Renninger, 2006).

Learning pathways through ecosystems often rely on learner interest, but youth in early stages of interest development may not be as likely to seek additional opportunities for learning as those with more developed interest (Renninger, Costello Kensey, Stevens, & Lehman, 2015). Therefore, how might informal science programs be designed to serve as more than just an onramp for interest and instead be designed to help deepen interest and to strengthen youth identity as environmental people? A learning ecosystem framework is a potentially powerful tool for designing and managing for environmental interest and identity development. However, the framework's potential has been underutilized.

1.2 A learning ecosystem framework

Interest and identity development happen throughout an individual's lifetime and across diverse pathways between formal, informal, and home settings (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2013). The complexity of where, when, and how interest and learning takes place has been described as a learning ecosystem by both educational researchers (e.g., Akiva, Kehoe, & Schunn, 2016; Barron, 2006) and practitioners (e.g., Poon, 2017). The concept of a learning ecosystem effectively helps communicate how learning happens across space and time as a dynamic process of interaction between a host of elements.

However, the theoretical underpinnings and application of this framework could be strengthened. The framework does highlight the dynamic and relational aspects of learning. But it typically treats learning ecosystems as complicated systems, rather than complex ones (Hecht & Crowley, 2020). By taking a deeper look and exploring the dynamic relational processes of the learning ecosystem, we may be better able to design systems that are able to describe this complexity and ultimately help us design and manage improved lifelong and lifewide learning opportunities (Falk & Dierking, 2018).

Relational processes are the unit of analysis in a number of social science fields. They are the focus of new materialist philosophy which draws upon physics to illustrate how even at the atomic and subatomic levels, relational processes inform action and agency (Barad, 2007; Fox & Alldred, 2018). Emphasis on relational processes over subject/object analysis is also used in practice theory (Spaargaren, Weenink, & Lamers, 2016) and network theory, where the concept of relationality is one where "entities have no essence in themselves, but their properties and boundaries are formed and shaped through their relations to other elements" (Vicsek, Király, & Kónya, 2016, p. 79). Applying the lens of relational processes to learning ecosystems requires moving away from thinking of the ecosystem as a set of interconnected pieces and towards viewing learning elements as existing through their relationship with each other.

This way of thinking is at the essence of ecology, which moved the biological sciences away from a focus on individual organisms and towards exploration of the interactions of living and nonliving components within systems (Horton, 2018). It is also a foundational component of approaches to science across numerous Indigenous communities (Kawagley, 2006). Applying this conceptual lens to learning mirrors how sociocultural theories acknowledge the importance of culture on individual learning (Gutiérrez & Rogoff, 2003). It extends this frame by considering the relational processes between a greater range of elements in the system, including nonhuman elements.

1.3 Place as a learning ecosystem actor

The focus of my dissertation is on how learning ecosystems connect natural and cultural communities to support environmental interest and identity development. My empirical work is centered in Pittsburgh, Pennsylvania, a mid-sized post-industrial city in Appalachia. Over the last 10+ years, Pittsburgh has worked to improve collaboration and networking for educational improvement (Semmel, 2015; The Sprout Fund, 2015). This emphasis on learning goes hand in hand with efforts to reinvent Pittsburgh as a “most livable city” (The Economist Intelligence Unit, 2018). This is part of a larger international trend of cities vying to be seen as leaders in technology and the environment – a trend that extends educational goals beyond schools and universities and into out-of-school learning spaces (Facer & Buchczyk, 2019). Here in Pittsburgh, the work has been cross-sector, with an emphasis on building a learning ecosystem that broadly encompasses both formal and informal places and is inclusive of a range of perspectives and values that extend beyond typical educational spheres (R. B. Stevenson, Wals, Heimlich, & Field, 2017). My work offers a systematic exploration of what learning ecosystems mean to this particular city because, as with all ecosystem work, locality matters.

Importantly, a place-based approach must adopt a critical lens that contextualizes place within sociocultural history and racial politics (Adams, Greenwood, Thomashow, & Russ, 2017). The United States has a long history of forces that sharply undermine much of the promise of cities as effective learning landscapes. The first was the displacement and erasure of Indigenous communities that historically lived in many of the places that are now urban centers in the United States (Bang et al., 2014; Dunbar-Ortiz, 2014). This was followed by the racial exclusion and housing segregation of Black peoples within cities, which is inextricably tied to segregated and inequitable schools (Rothstein, 2017). Both of these are manifestations of colonialism/capitalism, the logics of which maintain a sharp philosophical divide between nature and culture. These logics have been used to justify abuses of both land and those people characterized as less than human – predominantly Black and Indigenous peoples (Moore, 2016). It is a mindset that employs the settler colonial logic of *terra nullius* – the fiction that land is empty in order to justify dispossession (Tuck, McKenzie, & McCoy, 2014).

One way that urban communities, particularly poor communities and communities of color, experience the contemporary manifestation of these colonial logics is via gentrification (Paperson,

2014) and Pittsburgh is no exception to this (Kozak, 2014). Gentrification, although not directly tied to educational policy or implementation, has been shown to impact youth learning outcomes (Pearman, 2019). Another impact of colonial logics is on urban science education which is predominantly presented through the lens of European-derived ways of knowing and reinforces a construct of a nature-culture divide (Bang, Warren, Rosebery, & Medin, 2013). When educational structures ignore non-dominant ways of knowing that exist in communities, we enact a conceptual terra nullius.

But our cities are not empty lands, they are rich in natural and cultural histories. Despite the negative historical forces, cities remain uniquely suited to building rich learning ecosystems precisely because cities are naturally diverse. In fact, diversity is part of the foundational concept of a healthy urban community (Jacobs, 1961) and cities offer the potential for diverse peoples to interact in structured and unstructured ways and make significant connections with one another (Fullilove, 2013; Reichl, 2016) and the nonhuman natural world (Bang et al., 2014). However, when we erase or ignore existing human and natural communities, we undermine the potential for urban learning ecosystems to thrive.

A learning ecosystem framework is one potential tool for integrating place-based learning with science education in order to embrace both the natural and cultural histories of communities. The framework also helps to conceptualize the complexity of the factors impacting environmental interest and identity development. In this three-paper dissertation, I aim to explore this complexity across time and space. I also explore this complexity across species boundaries within the context of Pittsburgh as a place whose land, waters, flora and fauna all help shape learning. It is my hope that science education which explicitly renews relations between and among human and nonhuman nature might offer one pathway to bring our planet back to health (Bang & Marin, 2015; Haraway, 2016; Kawagley, 2006).

2.0 PAPER 1: UNPACKING THE LEARNING ECOSYSTEM FRAMEWORK: LESSONS FROM THE ADAPTIVE MANAGEMENT OF BIOLOGICAL SYSTEMS

(Manuscript published in Journal of the Learning Sciences; see Hecht & Crowley, 2020)

2.1 Abstract

An ecological framework is often used to describe the context for learning in educational research and practice. However, there is often a focus on descriptive aspects that frame the ecosystem as a complicated set of interconnected elements—but not a true complex problem. Acknowledging connections between ecosystem elements is not enough to affect the systemic change that the wicked problem of education requires. In this paper, we argue for moving toward a more robust framework that takes seriously the notion of learning happening via relational processes between system elements, and looks more deeply at the ways in which those dynamic elements are interacting in complex, multiscalar ways. We promote drawing more heavily from ecologists' understanding of biological systems, particularly the application of concepts drawn from adaptive management strategies used in the field of restoration ecology. We present an argument to decenter our field's typical focus on individual youth, just as ecologists have moved biology away from an emphasis on individual organisms. We postulate that decentering youth enables new ways of thinking about learning ecosystem design and management. We then explore three specific concepts used in adaptive management in ecology: ecotones, keystone and indicator species, and disturbance and resilience.

2.2 Introduction

An ecological framework is often used to describe the context for youth learning and development in educational research (Akiva et al., 2016; Bevan, 2016) and educational practice (Krishnamurthi, 2014; Poon, 2017). The framework is grounded in an understanding that learning relies on what Barron (2006) called "critical interdependencies across contexts" (p. 195). It is important to recognize the idea that learning experiences are best seen as connected across place and time, and that education can happen in a range of contexts in and out of schools. The idea of the ecosystem, which has often been used as an analogy, has been instrumental in helping to spread and shape these ideas.

In this paper, we argue for moving toward the use of a more robust framework that takes seriously the notion of learning happening via relational processes between system elements, and looks more deeply at the ways in which those dynamic elements are interacting in complex ways. By relational we mean that these processes reflect interactions between and among various elements of the learning ecosystem. Specifically, we promote the use of a learning ecosystem framework that draws more heavily from ecologists' understanding of biological systems, particularly the application of concepts drawn from adaptive management strategies used in the field of restoration ecology. This expanded framework could help inform the management of learning ecosystems that create interrelated elements that support overall learning ecosystem health and resilience (Falk et al., 2015). Our goal in writing this paper is not to unpack every potential concept from restoration ecology that might be used for learning ecosystem management. Instead, we are focused on a subset of ideas that we think resonate most strongly with current work on learning ecosystems. We propose enriching the concept of learning ecosystems by examining the vocabulary we use for elements of the system, reconsidering how we think about relationships between elements of the system, and refining approaches for describing and interpreting learning ecosystem function at different scales.

This paper is divided into two sections. The first section examines how the learning ecosystem framework is currently applied across a variety of learning settings, and proposes two conceptual moves to make further use of the framework: viewing learning ecosystems as complex systems rather than merely complicated and using scalar thinking as a tool for approaching this complexity. The second section focuses on extending the learning ecosystem framework by drawing upon ideas of adaptive management from the field of restoration ecology. We open with an explanation for why using the language and concepts of adaptive management might be a fruitful approach. We present an argument to decenter our field's typical focus on individual youth, just as ecologists have moved biology away from an emphasis on individual organisms toward a truly systemic view. We postulate that decentering youth enables new ways of thinking about learning ecosystem design and management. We then explore three specific concepts used in adaptive management in ecology:

- How might attention to ecosystem boundaries and ecotones support learning?
- How might we identify where to monitor and invest resources by considering "indicator species" and "keystone species" in a learning ecosystem?
- How might we better support resilience of systems by accepting constant change and preparing for natural disturbance?

2.3 Learning ecosystems as a lens

2.3.1 Current application of the framework

Efforts to explain the complexity of interactions between home, school, and community have been popularized by Bronfenbrenner's model of human ecology (1979). Bronfenbrenner's work brought about an important shift in psychology, drawing attention to the idea that individuals do not exist in isolation and instead are influenced by nearby elements, such as the home, and farther away elements, such as societal factors. The notion of how human ecology influences learning and development was refined over subsequent decades to explore learning that occurs outside of traditional classroom spaces.

Barron (2006) refined this framework by defining a learning ecology as "the set of contexts found in physical or virtual spaces that provide opportunities for learning." (p. 195). The National Research Council (2015) defines a learning ecosystem as: "the dynamic interaction among individual learners, diverse settings where learning occurs, and the community and culture in which they are embedded." (p. 5). Elements of this learning ecosystem include people (youth, family, educators, funders, etc.); places (schools, libraries, community centers, museums, hospitals, etc.); activities/resources (internships, programs, curricula, books, internet); and intangibles (politics, social services, the history of education in a community, culture). Note that in this paper, we will use the phrase learning ecosystem instead of learning ecology in order to emphasize our focus on systems. The idea of a learning ecosystem helps to frame the multilayered complexity of how learning occurs across different participants, settings, and times.

The learning ecosystem framework is now used ubiquitously across many different learning settings. It has been used to frame the impact of the physical space on learning, including the need for purposeful design (Herzog, 2007) and the need to consider places other than schools as learning spaces, such as libraries (Rettig, 2009), museums (Salazar-Porzio, 2015), and other community based and informal learning settings (Russell et al., 2013). The ecosystem framework has also been used to help characterize the kinds of virtual spaces that learners engage in (Berglund, 2009; Folkestad & Banning, 2010), as well as how those virtual spaces connected with bricks and mortar classrooms (Herro, 2016; C.-C. Lin, 2011). Use of an ecological framework can be seen in writings about the practice of distance learning (M. T. Miller & Husmann, 1996), and the need to be attentive to "digital divides" (Henning, Van der Westhuizen, & Diseko, 2005). The importance of connecting learning opportunities for youth is also an application of learning ecosystem analogies (Corin, Jones, Andre, Childers, & Stevens, 2017). The ecosystem framework has been used to draw connections between traditional classrooms and their communities in both preK-12 (Cekaite & Evaldsson, 2017) and higher education (Damsa & Jornet, 2016) settings. Recognizing this connection across the formal/informal educational sectors can surface issues of equity and justice in education by highlighting the ways in which home and community culture offer unique perspectives that can support learning (Gutiérrez, Bien, Selland, & Pierce, 2011), but may also reveal contextual challenges facing some youth as they engage in academic pursuits (Lee, 2017).

However, even when there is a strong emphasis on the complexity of learning environments, as in Barron's foundational work and myriad other pieces that use an ecosystem lens—including those focused on equity, such as Carol D. Lee's powerful call in her AERA 2010 address to look at interdependence across contexts (2010)—many authors, including ourselves, have often reverted to a less complex focus on individual learning experiences within the ecosystem, rather than exploring systemic, relational patterns. The current use of learning ecosystems is often by analogy and often portrayed in static, simple terms, rather than with the dynamic, complexity of biological systems (Falk & Dierking, 2018).

2.3.2 Not just complicated, but complex

Educational improvement is a “wicked problem”—it is chronic, complex, unlikely to be solved via linear solutions, and may benefit from collaborative and iterative refinement (Gomez, Russell, Bryk, Lemahieu, & Mejia, 2016). Recognizing this complexity means that we must accept that simple causal explanations for challenges in the educational system will not suffice (Jacobson, Levin, & Kapur, 2019). Problems like this require attention to the “collective impact” of multiple players within the learning ecosystem (Kania & Kramer, 2011). Lemke and Sabelli (2008) called for educational research that draws on models of complex dynamic systems. The field of restoration ecology, which uses adaptive management approaches, can provide one such model.

Currently, the descriptive aspects of the learning ecosystem framework often point to a view of the ecosystem as a complicated set of interconnected elements—but not a true complex system. However, if educational systems were merely complicated then surely policymakers, researchers, and practitioners would have been able to identify replicable approaches to solving educational challenges. The reason these challenges persist is because learning ecosystems are complex—by which we mean they are dynamic, non-linear, and unpredictable (Yoon, 2011); they are continually undergoing changes that amount to more than the sum of their parts (Johnson, 2008). Therefore, we cannot expect, as we might with a complicated problem, to come up with a set of instructions to solve educational problems and expect them to remain solved, nor can we easily replicate these efforts across space and time effectively (Snyder, 2013). The complexity of learning ecosystems is why merely acknowledging connections between ecosystem elements is not enough to affect the kind of systemic change that the wicked problem of education requires. Given this complexity, we do not believe the ecosystem framework is doing all the work that it could do for the field.

By taking a deeper look and exploring the dynamic processes of learning ecosystems, we may be better able to manage systems that offer more equitable lifelong and lifewide learning opportunities (Falk & Dierking, 2018). In particular, we propose using dynamic relational processes as the unit of analysis. By relational processes, we mean interactions between and among elements of the learning ecosystem including but not limited to youth, educators, families, and the material elements they engage with, such as classroom spaces or nonhuman nature. These relational processes can be observed as robust episodes of interaction, such as the verbal exchange of ideas between students in a classroom or a learner's connection to scientific content through the physical manifestation of phenomena, such as stormwater flow in a rainstorm. The ecosystem actor that we call "learner" or "student" necessarily exists only in relation to these other elements of the system; without these elements, there is no nameable entity of "learner". Therefore, we propose focusing on those relational processes and shifting the unit of analysis from learning as an individual outcome to learning as a process that exists because of the interactions between learning ecosystem actors.

The concept of relational processes is used in a number of fields. They are the focus of new materialist philosophy which draws upon physics to illustrate how even at the atomic and subatomic levels, relational processes inform action and agency (Barad, 2007; Fox & Alldred, 2018). A rejection of the distinction between subject and object in favor of an emphasis on relational processes between entities is also used in practice theory (Spaargaren et al., 2016) and network theory, where the concept of relationality is described as one where "entities have no essence in themselves, but their properties and boundaries are formed and shaped through their relations to other elements" (Vicsek et al., 2016, p. 79).

Applying the lens of relational processes to learning ecosystems requires moving away from thinking of the ecosystem as a complicated set of interconnected pieces and toward thinking of the ecosystem as a complex with elements that exist through their relationship with each other. This way of thinking is at the essence of ecology, which moved the biological sciences away from a focus on individual organisms and toward exploration of the interactions of living and nonliving components within systems (Horton, 2018). Applying this conceptual lens to learning mirrors how sociocultural theories acknowledge the importance of culture on individual learning (Gutiérrez & Rogoff, 2003). It extends this frame by considering the relational processes between a greater range of elements in the system, including nonhuman nature and place (Tuck & McKenzie, 2015). Using ecological thinking changes the way we see the ecosystem itself: it is no longer a collection of participants and learning places with separate essences that need to be connected for individual children. Instead, the learning ecosystem emerges as a constellation of intertwined and entangled elements, where learning happens through dynamic relational processes among the people, places, and stuff we find across/within/between school and out-of-school places.

2.3.3 Not just scaling up, but thinking across scales

In an article examining the intersection of educational research and design, Penuel, Fishman, Haugan Cheng, and Sabelli (2011) reflect that: "An enduring goal of research in education has been to identify programs that can reliably work in a wide variety of settings so that such programs can be scaled up to improve system-level outcomes." (p. 331). Often, when we talk about scale in the field of education, scale is raised in reference to improvement—to take what we see working in one program, one classroom, and bring it to scale. However, we know from policy analysis, that scaling up educational interventions is often less effective than the original application of the idea. Part of what is missing from the notion of scaling is that the focus can be on the unidimensional aspect of simply increasing numbers, when in fact a multidimensional approach would be more effective given the complex nature of the system (Coburn, 2003).

Scaling up in educational systems gets even more troubled when we acknowledge that only a small portion of our days are spent within formal, school-based learning environments. Even during the years of formal schooling, children have something like 80% of their potential learning time outside of classroom settings (Banks et al., 2007). This expansion of the scale of learning opportunities across an individual's life makes replication more complicated. Is success in a maker program at a library tied to the place "library"? Or is the success due to the relationship between educator and youth, which might allow the program to be replicated at a faith-based institution where equally strong relationships are fostered? The franchise model for replication, which struggles to be effective in schools, completely falls apart within the complexity of out-of-school learning and a broader learning ecosystem. Cohen and Garcia (2014) write, "Nearly all interventions that affect important outcomes are faced with the question 'How can it be disseminated on a wide scale?' … Instead one should ask 'Who can it help, and when and where can it help them?'" (p. 17). Reframing dissemination in this way recognizes the complex nature of educational interventions and the need for more localized and adaptive approaches.

Here is where applying ecological thinking to the notion of scaling can help. Ecology is a science of case studies—and the complexity of systems means that no two cases will ever be the same (Code, 2006). Therefore, the notion of replication with high fidelity to the original must be put to the side. Instead, we ought to accept local variation and pursue adaptive strategies, which are commonly used in restoration ecology and rely on ongoing monitoring and iterative changes (Society for Ecological Restoration, 2016). This type of approach can be seen in some educational work. For example, some Networked Improvement Communities have begun looking at the adaptive integration of ideas from one setting to another (Bryk, 2015; Cannata, Cohen-Vogel, & Sorum, 2017). Moving these approaches beyond school systems to learning ecosystems that include the full range of learning settings is an important next step toward building equity. However, even with adaptive approaches, we can be lured into thinking of scale as trying to make things bigger. But the scale is about a shift in perspective, rather than just a shift in size.

We know from biology that form, function, and size are inextricably linked. The early evolutionary biologist and scientist, JBS Haldane, addressed the challenge of scalar shifts in his essay "On Being the Right Size". In the essay, Haldane (1926) contends that an animal's size proffers different specific forms that allow for different functions. This structural scale variance, or the difference in functionality across scales (Roberts, 2016), is important to attend to. Biological ecosystems exist at multiple scales—from microscopic systems in the soil to forests that extend for hundreds of miles. They are also nested, with smaller ecosystems situated "inside" of larger ecosystems. The analog of this is when we consider a school classroom or an out-of-school program as a learning ecosystem unto itself that is nested within a larger regional learning ecosystem. The youth we are hoping to reach move across these nested ecosystems—from their classroom to their community to the regional network of learning opportunities. At each scale, there are elements that interact, supporting the flow of energy and ideas and opportunities for learning.

What does this mean for applying a learning ecosystem framework to education? Importantly, the relative sizes of nested systems do not require subordination of the smaller to the larger. While each system interacts with other systems, the smaller system may actually influence the larger system as much as the reverse occurrence.[1] For example, a microbial soil ecosystem is not subordinate to a massive forest ecosystem. In fact, in many ways soil drives the health of the forest system that it is nested within. We might also find that each system operates independently of systems that it is nested within or that are nested within it (Simon, 1996).

When we view a classroom or program in this light, perhaps that changes how we approach educational management. We might open up ways to consider multilateral interactions across scales and how these influence management techniques at the systems' level, instead of focusing on how larger systems impact individuals within the system. While researchers must draw system boundaries to aid in understanding, these boundaries are naturally porous and relational process and interactions work across scales in ways that can be difficult to parse out (Horton, 2018). To understand learning ecosystems, then, we need to push ourselves to think in multiscalar ways because the very nature of ecosystems is that they exist at both micro and macro scales in nested, but nonhierarchical, structures.

[1] Here we use smaller and larger to designate the perceived spatial relationship between say a classroom and a school. However, we also recognize that these relative terms serve to conceptually obscure the scalar differences of these different components of a system.

2.4 From analogy to framework

2.4.1 Drawing on adaptive management

Barron (2006) has suggested the potential for using the learning ecosystem framework as a design tool. The intentional design and management of robust learning ecosystems, in partnership with communities and both formal and informal educational institutions, is critical for fostering connected in- and out-of-school learning experiences. These experiences are too often only possible for more affluent members of our society because they often require fees or transportation that may be barriers for some (Falk & Dierking, 2018; Penuel, Lee, & Bevan, 2014). A next step in extending the learning ecosystem framework is to look beyond mere identification of elements of the system and toward the analysis of both structure and function of learning ecosystems (Falk & Dierking, 2018; Falk et al., 2015).

We argue that to effectively use this ecological framework for design and management, we might look more closely at the ways that ecologists have attempted to exert influence on biological ecosystems through the adaptive management strategies used in the field of restoration ecology. Ecologists use their ever-developing understanding of ecosystem forms and functions as tools for ecological management, from urban green spaces to national parks. We have chosen to focus on these overtly human-influenced ecosystems rather than on so-called "wild" ecosystems because we recognize that humans are constituent parts of all ecosystems—whether biological or learning. We therefore inevitably influence ecosystem health, sometimes purposefully, oftentimes inadvertently.

What might we learn from adaptive management strategies in restoration ecology that could be applied to the management of learning ecosystems in ways that could support healthier and more equitable ecosystem function? First, we begin by considering a fundamental element of ecosystems: they are defined by interrelationships between elements rather than individual actions. We then turn to the potential application of three concepts drawn from the adaptive management of landscapes: first we explore the role of boundaries and ecotones; then we consider measures of ecosystem health and suggest the use of keystone and indicator species; and finally, we consider the significance of disturbance and resilience.

2.4.2 Decentering individual learners

From Bronfenbrenner on, models of human ecology and learning ecosystems have often been represented visually with an individual at the center of the system, where impacts from the environmental context exert force on the individual, often depicted as a child (see Figure 1). This representation of learning ecosystems can be found in educational literature that connects school systems with informal, out-of-school learning (Bevan, 2016), and has also been used to describe domain-specific learning, such as STEM education (National Research Council of the National Academies, 2015). These diagrams work in the sense that they convey that no single influence accounts for learning and development. However, this persistent focus on youth as the center of the learning ecosystem undermines the potency of the ecosystem framework. It perpetuates the idea that learning happens at the individual level and that systemic inequity can be addressed by supporting opportunities for individuals.

Unlike in these diagrams, an ecosystem has no center. All elements of a system are influencers of and are influenced by their context; elements of an ecosystem can never be fully teased apart. For example, it is widely accepted in ecology that trees have important functional relationships with fungi, called mycorrhizae, which grow on tree roots. These fungi have been used to help characterize the expansive nature of complex systems (Engeström, 2007). In forest ecology, the relationship between mycorrhizae and trees is thought to support more than just the individual tree, and instead supports ecosystem function across multiple plants and mycorrhizal species (Ferlian et al., 2018).

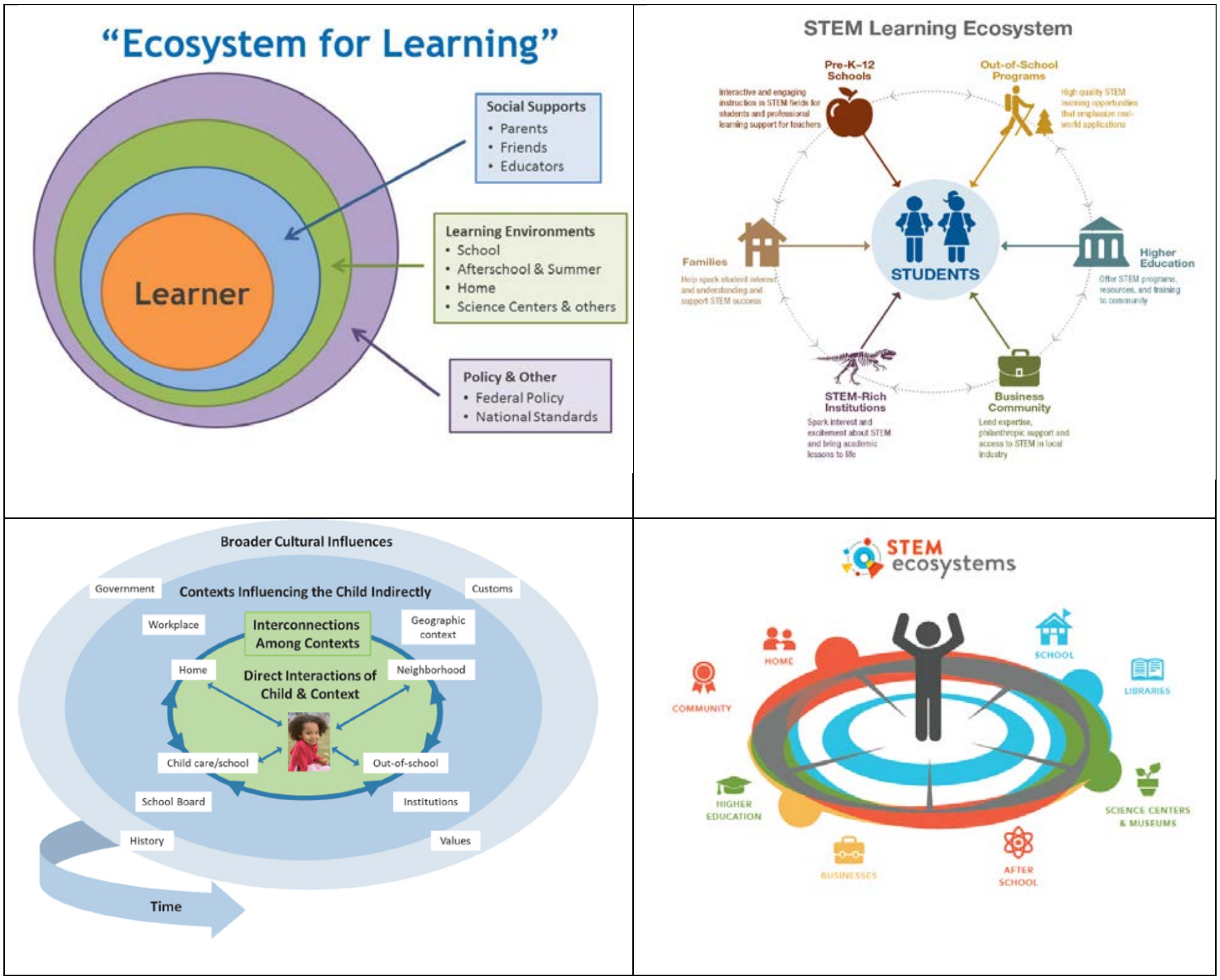

Figure 1. Common visualizations of learning ecosystems.

Images, clockwise, taken from websites for Afterschool Alliance (2014), U.S. Department of Education (2015), STEM Ecosystems (n.d.), and National Research Council of the National Academies (2015).

In fact, the very existence of individual organisms and "essential identity" has been called into question by ecofeminist theorists such as Haraway (2016) and by biologists, some of whom are using the term “holobiont” to describe the complex and persistent interrelationships between species (Gilbert, Sapp, & Tauber, 2012). This integration occurs across kingdoms, where bacteria and eukaryotes, including plants and animals, exist together in functional units. This has been shown to occur in humans, wherein bacteria inform critical functions and are part of an ecosystem housed within the human body. This emerging understanding suggests that we not only currently coexist with bacteria but have actually evolved in response to our connection with them (McFall-Ngai et al., 2013). We and the hundreds of species of bacteria in our gut are long-term partners; we are holobionts (Gilbert et al., 2012).

Similarly, individual children are not only influenced by elements of the learning ecosystem—they are inextricably connected to and part of those elements in ways that we are only beginning to understand. What might a decentering of the individual—a rejection of the notion of an individual learner as a unit of analysis—open up in terms of learning ecosystem management strategies? Sociocultural views on human learning and behavior have long argued that an exclusive focus on individuals, or even groups of individuals, fail to recognize and account for larger cultural practices that co-evolve with and co-create learning and development (Gutiérrez & Rogoff, 2003). The learning ecosystem framework, when tied more closely to ecological concepts, supports this approach to thinking about educational experiences in the context of a complex, integrated system. The functional unit for learning could, therefore, be made up of the relational processes between youth, parents, and educators in both schools and out-of-school settings, as well as the material elements of these spaces, ranging from pencils in classrooms to trees in landscapes. These forces do not revolve around an individual child as a learner—they are part of the child and the child is part of them because the child as a “learner” can only exist in relation to other learning ecosystem elements.

2.4.3 Attending to boundary crossings and ecotones

Recognizing that functional units of learning ecosystems operate within and across scales pushes us to consider how the boundaries between scales are crossed by energy, ideas, etc. For example, interest in science may be initiated in an out-of-school learning experience at a museum, be supported by a family member's parallel interest in the subject, and then get deepened through exposure to content in a school classroom (Crowley & Jacobs, 2002). Each of these learning moments is linked through the individual youth that is experiencing them, but they are typically depicted as distinct from one another in the learning ecosystem itself, with specific boundaries that are crossed by the youth.

However, we know from biological ecosystems that boundaries between different elements of the system can be fluid transition spaces, called ecotones, that have their own form and function. Transition spaces like this can be important spaces to monitor and manage because of the role they can play in supporting the health of adjacent systems. For example, the ecotone between a woodland and a river is a transition space that is called a riparian zone. The riparian zone provides an important buffer during rain events, filtering excess nutrients and pollution from water that is draining down and across the land; riparian areas also absorb rising waters from the river itself (Ricklefs & Miller, 2000). This ecotone's position between the two systems helps to support them both—it helps regulate water quality and quantity in the river and it reduces erosion and degradation on the land. Therefore, the riparian zone can become a tool for ecosystem management that can help to improve other systems that are adjacent to it.

What do transitional boundary zones in a learning ecosystem look like? One example of an ecotone at the scale of a school or program is the space just outside of a school or program building. Although youth may not be engaged in a formal learning activity in this space, the space still serves as both the introduction and coda for learning during the school day or program experience. How does passage through this ecotone inform a learner's engagement with education once they enter the building? How might it reinforce what has already been learned?

An ecotone like this also interacts with the social geographies that youth move through. For example, a youth may be interested in participating in a museum summer program. Even if transportation or cost are eliminated as barriers to participation, there may still be sociocultural factors, such as a museum's location in a neighborhood that may be unwelcoming for youth or a youth's perception that the museum itself is not welcoming (Dawson, 2017). This kind of transition—from one cultural space to another—is also an ecotone that should be considered in learning ecosystems.

Attending to ecotones could help promote successful learning pathways, which have been shown to be an important component for long-term interest and identity development (Azevedo, 2013; Crowley et al., 2015; Hecht et al., 2019). For example, what is the ecotone between school and out of school? Is it home? Peer groups? Community? All of these? How might care and attention to ecotones support healthier elements that enable learning throughout a regional learning ecosystem? Opportunities for learning moments should not be reserved for the classroom or program. Educators could be trained and supported to encourage ecotone interactions across and between school/out of school experiences. And deliberate management of ecotone spaces could help support learning goals.

2.4.4 Managing and monitoring for ecosystem health

We propose using the ecological concept of keystone species as a management tool. Keystone species are identified by their strong impact on the flow of energy and matter (the trophic cascade) of an ecosystem. They are drivers of ecosystem health, potentially impacting many other species across the system. Examples of keystone species in biological systems vary in size, but top predators such as wolves in Yellowstone are often used as common examples. By reintroducing this keystone species into the ecosystem, the wolf helps to stabilize the system overall by hunting and eating grazers, which thereby reduces pressure on plant material. Of course, the keystone also relies on other ecosystem elements, but overall, their presence has a strong influence on improving habitat and health for species throughout the system, sometimes directly and sometimes indirectly (Ripple & Beschta, 2004).

We hypothesize that, at the program scale, well-trained, caring, knowledgeable, and connected educators can function as a keystone. When we invest in the development and professionalization of educators and educational leaders, benefits for youth learning radiate through the system. Here, we mean more than just teachers; we mean the full range of adults, in and out of school, who interact with youth as part of the larger system. While school-based teachers may struggle to receive fair compensation and meaningful professional development, out of school educators are even less professionalized and have fewer training opportunities (Yohalem & Pittman, 2006). To support a healthy ecosystem, we must make investments in educators working throughout the system.

By using the concept of keystones as the focus for resource allocation, we ought to be able to attend to the elements are that are driving the flow of energy and matter through the learning ecosystem. At the regional scale, we might think of intermediary organizations as the keystones of the learning ecosystem. When these organizations are well supported, they are key to building capacity in learning ecosystems (Penuel et al., 2011). This kind of “trophic cascade” of energy from the intermediaries to the program providers to the youth means that we can make focused investments of time and energy in intermediaries and should see benefits at relatively distal points.

So where does that leave youth? Maybe we consider youth as indicators which tell us something about the health of an ecosystem. For example, in biological ecosystems, some species, such as the mayfly, are only found when there is little pollution. Therefore, the presence or absence of mayflies in small streams can be used by ecologists as indicators of healthy water quality (Hodkinson & Jackson, 2005). However, an ecologist who is working to achieve healthy water quality is more likely to focus on preventing pollution at the watershed scale than on specific micro-interventions for improving mayfly habitat. They understand that the reduction of pollution is an indirect but effective tool for habitat improvement overall and will look to the mayfly as a sign that their intervention upstream is working.

Just like with the mayfly in a small stream, when youth are thriving, interested, and learning in a classroom, neighborhood, or informal learning program, we know the system is healthy. When they are struggling, we know the system is not healthy. Seeing learners as indicators could allow educational researchers to focus on youth as critical barometers of ecosystem health, while shifting energy away from creating interventions that target youth outcomes. The reorientation could promote more "upstream" approaches to improving a learning ecosystem, such as creating more opportunities for young children to develop interest during informal learning activities, stronger brokering of opportunities by educators and parents, and greater alignment between in and out of school experiences.

The idea of indicator species can be applied at a larger scale as well. At a regional scale, we might view educational organizations, e.g., schools, community groups, museums, as indicator species. The presence of well-functioning educational organizations can provide a good measure of the health of the regional learning ecosystem overall. However, overemphasis on investing in individual organizational success can undermine resource allocation across the system. Instead, we could look upstream for other points of intervention that allow for strategic resource allocation—of human, social, and financial capital—that can effectively support the health of the ecosystem overall. In a learning ecosystem, therefore, we might use keystones to guide resource allocation and indicators to help measure impacts.

2.4.5 Disturbance and resilience

Ecosystems are constantly changing and shifting, whether they are biological ecosystems or learning ecosystems. As with other complex management endeavors, we must avoid prescriptive outcomes that do not account for the system's dynamic nature (Simon, 1996). Instead, when working with learning ecosystems, we could adhere to the notion of adaptive management, which is both flexible and responsive (Groom, Meffe, & Carroll, 2006; Society for Ecological Restoration, 2016). Adaptive management recognizes that there while there may be constant elements within the system (e.g., students go to school from kindergarten through 12th grade) there is also abundant and constant change within the system that cannot be controlled (Spillane, Gomez, & Mesler, 2009).

One of the forces for dynamic change in a biological ecosystem is natural disturbance. While these disturbances seem destructive on the surface, they also serve to open up opportunities. Natural disturbances may be relatively small, such as a mature tree that falls and thereby opens up space in the forest canopy letting in light and allowing new plants to grow and thrive. There are also large natural disturbances, such as a hurricane or wildfire, that may do extensive damage to a system, completely reshaping major landscape features such as landforms and river pathways.

Whether large or small, a biological ecosystem's ability to rebound from natural disturbance and maintain overall health is often a measure of what is called its resilience (Society for Ecological Restoration, 2016). So, what do we know about natural disturbance and resilience in biological ecosystems that we might apply to learning ecosystems?

For one—disturbance is not bad. In fact, it is a necessary force in dynamic systems, allowing for new species to find space for growth. In a learning ecosystem, we might see new ideas flourishing after the natural disturbance of a leadership change. A natural disturbance like this might also reveal weaknesses in the system. If the school or organization does not rebound, or is not resilient, what is fundamentally problematic in the system? Using an ecological frame forces us to look beyond the individual leader—again, we are decentering individuals here—and toward systemic reasons why the natural disturbance may have been problematic. In the case of leadership change, the challenge for resilience maybe that support staff within the organization were not empowered to make decisions and therefore are not able to function when the leader shifts. An organization that has spread responsibility and control to actors throughout is more likely to be resilient when leadership changes (Hargreaves & Fink, 2004).

Secondly, local distinctions matter. Each type of biological ecosystem has its own type of natural disturbance. For example, fire is a primary natural disturbance in forests in the Western US, whereas wind burst might be more typical for a forest in the Appalachian region. Species and ecosystems adapt to these specific disturbances. When ecologists recognize what the natural disturbance is, they can use that to inform management decisions that can support resilience in the system when the disturbance inevitably comes. For example, if a hurricane is a likely disturbance, an ecologist might recommend building up and supporting dunes that help to protect the land from storm surges. Similarly, we might define different types of learning ecosystems, such as a STEM ecosystem or an out-of-school arts ecosystem. These different systems are also likely to have different potential disturbances. For example, a STEM ecosystem is likely to include schools, which are affected by the disturbance of governmental policy changes. In contrast, an out-of-school arts ecosystem may be more likely to need to weather a change in philanthropic funding as a disturbance.

Understanding local conditions, and the likely coincident natural disturbance, is critical for supporting the resilience of learning ecosystems. Learning ecosystems are shaped by the capacity of local actors, sociocultural history of the community, and more. Therefore, management of local learning ecosystems must take local conditions into account. This can help education leaders to better anticipate the specific types of natural disturbance that may occur and support efforts for planning and responsiveness. If you know that a hurricane is coming, you might choose to evacuate. If you know that you have a shortage of well-trained out-of-school educators, you might work to improve systems for recruitment, training, and retention. Defining what a thriving, resilient learning ecosystem looks like holds implications for adaptive management of that system. Two key components for supporting resilient learning ecosystems, therefore, are (1) accepting that natural disturbance will occur and (2) being attuned to the ways that these disturbances are locally contingent.

2.5 Conclusion

When we recently asked a program officer from a large regional foundation about their goals for educational funding in the coming years, they responded that they wanted to support a "more networked ecosystem" for learning. This vision of a high functioning ecosystem that supports and connects learning across formal and informal spaces has become a kind of holy grail for what it will take to manage more effective and equitable educational experiences for youth. In fact, the phrase learning ecosystem has become so embedded in talk amongst educational funders, providers, and researchers that the program officer provided no explanation of what they meant by a “more networked ecosystem”, and we nodded in assent—of course, this should be a goal.

However, unpacking the learning ecosystem framework reveals ever-deepening layers of complexity. In this article, we began by arguing for the importance of considering learning ecosystems as complex and multiscalar. We also called for decentering and recasting youth from lead actors to players in an interactive system. We believe this shift could help us manage learning ecosystems in ways that move beyond creating opportunities for individuals and toward supporting the relational process that supports overall learning ecosystem health and resilience. By emphasizing these relational processes, the learning ecosystem framework can support efforts to shift away from policies and practices that rely on the myth of individual meritocracy and toward those policies and practices that can begin to address more systemic causes of inequity and injustice.

For practitioners and policymakers, the decentering of individual learners opens up a dialogue about how learners are interconnected with the people, places, and stuff that they interact with in learning ecosystems. Moving our focus away from individual learners (currently treated like individual organisms) to learners as groups (analogous to a species) connected with other ecosystem elements (as holobionts) gives us tools to think about how to undertake educational management as a systems problem and how to use an adaptive management approach. A richer use of the learning ecosystem framework might help us achieve a deeper understanding of system structures and interrelationships between entities (Falk et al., 2015). It may lead to more nuanced attention to scalar shifts between different levels of learning ecosystems and force us to accept recurring and sometimes dramatic disturbances to local systems. If we accept disturbance as a fundamental and necessary part of learning ecosystems, how might policymakers and funders support the management of systems that can be more resilient to these changes? And how might practitioners rethink how to support connected learning pathways, how to train educators, and, importantly, how communities and stakeholders can collectively work toward and invest in healthy regional ecosystems that are equitable, accessible, and effective?

For educational researchers, using the learning ecosystem framework more robustly with a focus on relational processes is a potential tool to support calls to decolonize educational research and embrace what Patel (2015) has called “a research stance that used holistic ecologies as the default form.” (p. 36). This is not to say that research should never attend to how people learn at the individual level, but rather that for the larger goal of sustainable, just, and equitable educational improvements, our approaches need to be sensitive to systems that are more complex and multiscalar than we have been thinking about. One difficulty will be how to home in on what tools can be used for conceiving of and monitoring relational processes within complex systems. For example, how might relational processes be observed and measured both qualitatively and quantitatively? How might the field understand the limits and potential of natural disturbances? In Barron’s (2006) foundational piece on learning ecologies, she rightly points out that designing studies that are able to address this complexity is a key challenge. If we want to assess the health of learning ecosystems, we still have some work to do to develop the appropriate research tools for this.

We also recognize the potential pitfalls of leaning too heavily on an ecosystem framework. One reflective reviewer perceptively asked if relying too greatly on concepts from biological systems might actually undermine our goal of attending to equity, since biological systems do not have inequities the way cultural systems do. But both biological and learning ecosystems can be healthy or unhealthy, highly functional or less so. In our view, an unjust and inequitable learning ecosystem is an unhealthy one. An ecological frame offers the benefit of purposeful and adaptive intervention to address those inequities.

Finally, we ought not to believe that we can control this setting, any more than we ought to believe we can control a biological ecosystem. In fact, intervention as a design approach may not make sense when we are thinking about learning ecosystems. Perhaps we need to recast how we think about learning ecosystem design altogether, focusing instead on adaptive response to chaos. As the early ecologist, Egler (1977), noted: “nature is not more complex than we think, it is more complex than we can think.” (p. 2) The complexity of learning is what makes the ecosystem framework so powerful; both biological and learning ecosystems are equally more complex that we can think. Consider the layers of human experience, emotion, capacity, the natural and built environment that we learn in, the cultural and personal histories that impact every learning experience. Given this complexity, letting go of control and being responsive to chaos and emergent phenomena is key. While this prospect may feel difficult and humbling, we believe that using an expanded learning ecosystem framework can help us make better use of the tools at our disposal.

3.0 PAPER 2: BECOMING A NATURALIST: INTEREST DEVELOPMENT ACROSS THE LEARNING ECOLOGY

(Manuscript published in Science Education; see Hecht, Knutson, & Crowley, 2019)

3.1 Abstract

Engagement with and study of nature is increasingly important for science literacy and civic engagement. Spurred on by challenges of the Anthropocene, many informal learning institutions are exploring how their collections, programs, and scientific expertise can be mobilized to create new naturalist learning pathways for children and youth. In this paper, we explore retrospective life histories of 18 adult naturalists to examine experiences that they recall supporting their interest development in the natural world. Drawing on interest and informal learning literature, our analysis reveals how elements across the learning ecology, including school, family, and out-of-school learning, work together to support the development of naturalist practices and identities. We found that interest development in nature occurred across the learning ecology and that expression of situational or individual interest depended on the participants' age and the type of learning experience. A closer examination of three individual cases—a serious amateur naturalist, an environmental educator, and an ecologist—reveals some of the nuanced ways that interest in nature arises, is maintained, and can eventually develop into a deep, lifelong naturalist identity. We consider implications for how one might conceptualize and support informal learning pathways that involve deep engagement with and connections to nature.

3.2 Introduction

Over the last 40 years, a declining emphasis on natural history in the sciences has resulted in calls for the biological sciences to re-embrace a naturalist approach through direct engagement with the natural world (Dayton, 2003; Noss, 1996; Ricklefs, 2012). At their core, naturalists get into the field—out into the natural world—to apply the traditional skills of observing, recording, and interpreting species and natural processes (Grant, 2000; Noss, 1996). The study of the details of nature also demands an understanding of how organisms coexist and interact; and this kind of systems thinking can be applied to a variety of topics, from human health to land conservation and management (Charles, 2009). We suggest that the study of nature matters today more than ever in science education. The complex environmental challenges we face—from local water quality to global climate change—require an understanding both of the processes that drive natural systems and most importantly the role that humans have played in influencing changes to the natural phenomena (Tewksbury et al., 2014). Spurred on by these challenges of the Anthropocene, many natural history museums are actively exploring how their collections and expertise can be mobilized in the long-term community and educational engagement to create new naturalist learning pathways for children and youth (Dillon et al., 2016; Watson & Werb, 2013).

With this larger movement in mind, the Carnegie Museum of Natural History and the University of Pittsburgh created a research practice partnership to explore how the museum might conceptualize and support the development of a 21st century naturalist, which we broadly defined as the kind of scientifically and environmentally literate citizens who are prepared to think critically about some of today's most pressing environmental challenges. More important, our notion of a contemporary naturalist is of someone who embraces urban environments as part of the natural world and who will utilize these spaces as places to engage and inspire others

(Tewksbury et al., 2014). We envision that 21st century naturalists are able to understand global interdependencies, have the skills to make local-to-global connections, and are ecologically minded civic actors at the local scale (Fleischner, 2011; Sobel, Gentile, & Bocko, 2014). By engaging youth in nature and the environment as part of science education, we hoped to broaden participation in science and deepen scientific literacy (Charles, 2009; Tewksbury et al., 2014; Wals, Brody, Dillon, & Stevenson, 2014), while also exploring how informal science education can support general 21st century thinking skills, such as creativity, critical thinking, and synthesis of ideas across interdisciplinary fields (NewKnowledge, 2013; Sobel et al., 2014).

To identify the kinds of informal and formal educational experiences that might be important in developing 21st century naturalists, our research practice partnership decided to conduct retrospective life histories with adults whose vocations or avocations embody deep connections to nature and naturalist practices. As our partnership was focused on creating programs for children and youth, we decided to focus the retrospective interviews particularly upon the question of how these adults initially became interested in nature when they were children and how that interest developed over time.

3.2.1 Interest development

The question of how interest is initiated, sustained, and eventually developed into fully formed individual interest and identity is an important one for education (Ainley & Ainley, 2015; Alexander et al., 2015; Bathgate et al., 2014; Hidi & Renninger, 2006; Krapp, 2002). Interest is a concept and word used in daily vernacular to describe a feeling of attraction or excitement for something outside of ourselves. It contains an implicit nod to learning—interest embodies the desire to get to know more about something or someone. Interest throughout the course of one's life is central to learning in both in and out-of-school settings, especially for students from low-income, minority backgrounds who have historically been underrepresented in the sciences (Bang & Marin, 2015).

Interest in science has been attributed to both school experiences and self-initiated experiences (Maltese & Tai, 2010). Contextualization, personalization, and choice have all been shown to have strong effects on elementary school students' depth of engagement in learning (Cordova & Lepper, 1996). Topic interest has also been shown to increase positive affect, which, in turn, increases the student's persistence to learn (Ainley, Hidi, & Berndorff, 2002). This topical relevance has been shown to be especially helpful for increasing both interest and performance in science for high school students with low expectations of success (Hulleman & Harackiewicz, 2009). Connecting science information to students own experiences (Basu & Barton, 2007) and community values (Bang & Marin, 2015) also support sustained interest in science.

Much of the work examining interest is done in studies conducted in school or school-like settings (Ainley et al., 2002). However, informal learning settings, such as science museums and science clubs, have also been shown to trigger interest (Azevedo, 2011, 2013; Dohn, 2011) and increase engagement in science material and knowledge acquisition (Martin, Durksen, Williamson, Kiss, & Ginns, 2016). Field-based, informal environmental education and nature exploration have also been shown to support science interest development (Zoldosova & Prokop, 2006).

Models of interest development in science have been empirically tested in different timescales—from a short-term structured learning activity (Dohn, 2011) to a semester-long intervention (Hulleman & Harackiewicz, 2009) to an analysis of 3 years of interest development (Alexander, Johnson, & Kelley, 2012). However, short-term learning experiences do not reflect the complexity of lifelong learning (Krapp, 2002). Interest develops as a result of numerous experiences that occur over a lifetime (Ainley & Ainley, 2015; Barron, 2006; Crowley et al., 2015) and learning is often experienced outside of school settings (Crowley et al., 2015). Learning happens across a variety of sectors and includes structured learning opportunities, such as school-based learning, and semi- and unstructured learning that occurs through out-of-school time experiences with family, friends, and at informal learning institutions. This broader set of temporal and structural experiences, which reflect the complexity of learning throughout an individual's lifetime, has been called a "learning ecology" (Barron, 2006; Crowley et al., 2015). Given the evidence for interest development in both in and out-of-school settings, we consider here how experiences across the learning ecology contribute to longer-term interest development.

In the context of this broader learning ecology, Barron (2006) has proposed three conjectures on learning and interest development: (a) that there are a variety of things that can spark and maintain interest, including media, conversations, and experiences; (b) that individuals make choices about the learning opportunities they experience based on their developing interests, provided that the opportunities for these experiences are afforded to them; and (c) that interest-driven learning naturally crosses boundaries between types of learning environments. She argues that formal and informal out-of-school learning should not be sharply compared and contrasted. Rather, they both form important components of the overall learning ecology. She stresses that adolescents, in particular, are involved in learning across many settings and that this is a developmental time when individuals begin to create their own learning opportunities. Barron also asserts that being engaged in many activities, along with the interactions between these activities, is key for identity formation. Studies that have examined longer-term interest development also support the importance of elements throughout the learning ecology, in particular, the role of family (Bricker & Bell, 2014) and informal engagement (Azevedo, 2011, 2013) with science content.

To deepen understanding of the complex and layered interest that develops over the course of an individual's entire childhood, we explore how Hidi and Renninger's (2006) four-phase model of interest development can be applied at this longer timescale. Given the length of time that we are examining, and the recollected nature of life history interviews, we suggest that looking at the two higher order categories of situational and individual interest, rather than also including the subcategories, are most useful at this grain size. Situational interest is described as including "focused attention and positive feelings" and is fostered and maintained primarily through environmental factors. It is often described as a momentary spike in interest, but can also lead to interest development over time (Azevedo, 2018). Individual interest, which includes positive feelings, but now also includes value and knowledge, reflects a predisposition to want to engage with domain-specific content. This individual interest does persist over time and has been shown to arise from regular situational interest experiences (Palmer, Dixon, & Archer, 2017). According to the model, each phase of interest development is sequential; for example, triggered situational interest could lead to maintained situational interest. This could then lead to emerging individual interest, which might culminate into well-developed individual interest.

3.2.2 Project overview

This study examines the retrospective life histories of professional and serious amateur naturalists. We trace how our participants remember their interest growing over time and identify elements of the learning ecology that supported situational and individual interest. We also examine transitions between these two phases of interest and trace overall progressions from initial interest to a fully formed naturalist identity. Although life history data are necessarily shaped by the subjective recollections of participants, the data can provide a unique perspective on long-term learning pathways that are otherwise quite difficult to study, both in terms of engagement with the environment (James, Bixler, & Vadala, 2010; K. T. Stevenson et al., 2014; Williams & Chawla, 2016) and in terms of engagement with science (Bricker & Bell, 2014; Crowley et al., 2015; M. G. Jones, Corin, Andre, Childers, & Stevens, 2016).

We analyzed life history interview data to attend to the ways in which individuals perceive their own interest development and when they believed their interest transitioned from relying on external supports to embracing an internal and abiding naturalist identity. Thus, our analysis focused on identifying episodes of situational and individual interest in the life history and charting the larger trajectory of how the two interact during the development of a lifelong connection to nature. We recognize the limitations of relying on individual memory and interpretation of events but pursued this approach because of the potential benefits of exploring an extended look at interest development. Our study is guided by three research questions:

1. How might elements across the learning ecology support and maintain interest in nature?
2. Can we identify moments of situational and individual interest in these retrospective accounts, and is there evidence of how long-term connections to nature developed from these situational and individual episodes?
3. How do adult naturalists perceive and describe the genesis of their lifelong connection to nature?

3.3 Methods

3.3.1 Participants

The university-based researchers began by closely collaborating with educators and scientists at the museum to identify broad categories of naturalists and potential participants for this study. To develop the categories, our team discussed the ways in which we have observed adults engaging deeply with nature both as professionals and amateurs. We included amateurs because there are naturalists who spend abundant time outside of work pursuing nature-based activities and gaining considerable naturalist skills, such as species identification. Although they may not be connected to nature professionally, these serious amateur naturalists also often share their knowledge with the broader community through activities, such as leading walks or writing blog posts about natural history.

We then refined this list of vocational and avocational engagements with nature until we agreed on seven categories to explore further: (a) applied scientist (e.g., ecologist working for parks organization); (b) research scientist (e.g., ornithologist working for research institution); (c) environmental artist (e.g., print-maker with emphasis on natural history); (d) environmental educator (e.g., education director for environmental nonprofit); (e) serious amateur naturalist (e.g., avid birder); (f) farmer/gardener (e.g., urban farm manager); (g) environmental community organizer (e.g., green jobs advocate). After the interviews were completed, we reevaluated the 21st century naturalist categories based on the interview data and added an eighth category—environmental designer (e.g., landscape architect)—to reflect an identity described by several of the participants in terms of how they interact with nature.

Our research practice partnership includes people who have worked extensively with naturalists in the region through both educational and scientific endeavors. Drawing on this knowledge, we purposively identified 48 potential interviewees spread across each of the seven naturalist categories. We continued to work as a team to prioritize potential interviewees that would provide diverse representation across the naturalist categories, genders, ages, and races. In particular, the team was looking to interview individuals that reflected what we defined as 21st century sensibility toward natural history—that is people who focused on urban areas, were from minoritized backgrounds, or included other disciplines in their work, such as art. This process led to a potential pool of 21 interviewees that reflected a diversity of age, gender, and race distributed across each of the seven naturalist categories. Of the 21 possible interviewees, three declined to participate in the project. After conducting interviews with the first 18 participants we found that we were hearing consistent themes and had reached data saturation. Thus, we decided to conclude the data collection rather than conduct additional interviews.

The final sample consisted of 18 adult naturalists, all living in the Pittsburgh region and all engaging regularly with nature either professionally or as serious amateur naturalists. The sample was fairly evenly split between women (10) and men (8). Participants were asked to identify their racial and ethnic background. Of the 18, 10 were identified as White, 5 as African American, 1 each as Latinx, Asian American/White, or Latinx/Black. The mean age of participants was 47; the minimum age was 24 and the maximum age was 68. The largest concentration of participants was between the ages of 35–44 (six total) and the remaining were fairly evenly distributed across other age brackets.

3.3.2 Interviews

All naturalists participated in 60–90-min two-part semi structured life history interviews that were recorded and transcribed for analysis. The first part of the interviews, which are the focus on this paper, were life history interviews during which interviewees were asked to explore formative nature-related experiences from early childhood through college.[1] Life history interviews, derived from Crowley et al. (2015) earlier work examining life histories of scientists, began by asking interviewees to describe when their interest in nature first emerged (see Appendix A). We then probed further for descriptions of the type of community they grew up in and asked them to consider how that may have influenced the type of outdoor play they engaged in, for example, “How did nature experiences figure in your experience of those places?” To explore the influence of family on their interest development in nature, we asked questions such as, “How did your family support your interest in nature?”, “Are there specific memories that you have with family members that helped shape your attitude towards nature?,” “What kind of relationship do your parents have with nature?,” “Did your family do any activities with you that involved nature?” In particular, we probed for any examples of family-initiated activities they may have participated in, such as gardening or hiking. We also asked them to reflect on any siblings’ adult orientation to nature to gain a sense of the parental influence on other members of the family.

The next section of the interview included a series of questions about other types of informal nature experiences, such as out-of-school programming like scouting; visits to informal educational institutions, such as museums or nature centers; and exposure to media that had a nature focus, such as magazines or television programming. We also asked them to systematically recount all school-based nature experiences. For this, we began by asking about elementary school experiences and then methodically moved through each level of schooling including middle school, high school, and any collegiate or post collegiate experiences with nature they may have had in the classroom or through courses they took. We also explored any relationships with nonfamilial mentors that may have influenced the development of their interest in nature.

These retrospective accounts focused on key moments and experiences throughout each naturalists' development that they recalled and identified as initiating or supporting their growing interest in the natural world. Questions probed deeply on when and where participants perceived their interest developing and, specifically, asked naturalists to consider those defining memorable experiences with nature that they believe led to their adult interest and identity as naturalists. For the three individual cases that are explored later in this paper, we invited each of the project participants to review these narrative accounts for accuracy and meaning; all names are pseudonyms.

3.3.3 Survey

Following the interviews, all 18 interviewees were asked to complete a follow-up survey. The primary focus of the survey was to get inputs from these naturalists on the types of programming that the natural history museum should design to support the development of future naturalists. We elected to include these in a follow-up survey, rather than in the interviews, to allow the participants time to reflect and consider how their experiences might support future program strategies. In addition to programmatic questions, we asked the participants to self-identify some specific descriptive characteristics, such as demographics and employment. (We supplemented this employment information with basic information derived from organizational websites.) We also asked participants to select which of the naturalist identities best reflected their current work in the field. They were able to choose up to three categories and were given the option of creating their own category. All eight categories were selected by at least one of the interviewees and most interviewees self-identified as belonging to two or more of the naturalist categories (Table 1)

Table 1. Self-identified naturalist identities of each of the 18 participants (up to 3 total)

Current position (most recent position if retired *)	Applied scientist	Community organizer	Environmental artist	Environmental designer	Environmental educator	Community garden manager	Research scientist	Serious amateur naturalist
Adjunct Professor of Art			✓		✓			
Artist			✓		✓			✓
Associate Professor of Landscape Architecture			✓	✓				
Community advocate		✓			✓			
Conservation Planning Manager	✓						✓	
Design Manager				✓				
Director, Conservation and Field Research	✓						✓	
Director of Education					✓			
Director of Information Technology *								✓
Executive Director	✓	✓						
Facilities Coordinator			✓			✓		✓
Naturalist Educator					✓			✓
Program Associate for Educational Projects		✓			✓			
Research Assistant *						✓		
Senior Restoration Ecologist	✓			✓				
Senior Hydrologist		✓		✓	✓			
School Garden Coordinator			✓		✓	✓		
Teaching Artist, Educator, Environmental Artist			✓	✓				
Total for each identity	**4**	**4**	**6**	**5**	**8**	**3**	**2**	**4**

3.3.4 Coding

Our coding of the data was iterative and involved several rounds of transcript review, code development and modification, and research team discussion about code application (Saldaña, 2016). To begin, we simultaneously read and listened to all 18 interviews to identity broad patterns in the data, which we derived both from answers to specific questions (e.g., “What were some experiences you had with nature through elementary school?”) as well as emergent themes (e.g., type of independent outdoor time play). Given that these are life history interviews, we evaluated how participants described important moments in their pathway and considered the characteristics and patterns of these experiences. After careful review of these patterns, we then developed a preliminary coding scheme and imported the data into the computer-assisted qualitative data analysis software program Dedoose to code the transcripts. This first round of codes included the types of nature-based experiences, such as family led, school-based experiences, out-of-school time programming, or independent activities; along with reflections on relationships of influence, either positive or negative, with family or nonfamily members. Team review of these codes led to a tightening of code descriptions and applications.

Our final codes included three broad categories for engagement with nature: those that took place out-of-school with some structure via family or programs, those that occurred in school, and those that took place out of doors, but independently (Table 2). To better characterize out-of-school activities, we created secondary codes for four types of out-of-school experiences: family activities, institutions, media, and programs, which included certificates. Experiences with nature that were independent and not at all facilitated by an adult or program were coded as “independent outdoor time.” For both of these sets of codes, estimated age period (e.g., early childhood, etc.) was coded when clear in the transcript. It was not possible to code for age for approximately one-third of these experiences because the nature of the experience was continuous over several stages or the age period was unclear. School-based experiences were coded separately and each educational period (e.g., elementary school, etc.) was identified. We also coded all participants’ reflections on adults that they perceived as playing an important role in their interest development.

Table 2. Code descriptions for nature engagement with example excerpts.

Primary & secondary codes	Code description	Illustrative example excerpts
Out-of-school	**Any type of out-of-school experience with nature that is mediated by some educational structure, such as family, program, or media**	
Family outdoor activity	Family-led semi-structured outdoor experiences such as hiking, camping, and gardening	"I guess it's state game land, but we could pull off and there's a lake there and we'd sometimes just stop there and fish on the way home for an hour or so."
Institutional visit	Visits to institution that uses the built environment and is designed for learning, such as museum, nature center, science center; often family-led	"We had an annual trip to the [natural history museum] and that was- that was a part of our growing up."
Media engagement	Indirect engagement with nature through media such as magazines, television, books, etc.	"We had field guides. We had all those Peterson guides for birds and rocks and everything and such."
Program activity	Programs with informal education or youth institutions such as scouting, summer camps, or museum programs	"I ended up off and on participating in earning badges through Girl Scouts. All of them, yeah, are like outdoors stuff. Either pitching tents or how to make proper fires…you know, like a warming campfire versus a cooking fire."
In school	**Experiences with nature through formal schooling, such as lessons or projects done as part of classes, that take place either indoors or outdoors**	
Elementary school	Nature experiences through an elementary school class	"I had a third-grade teacher that had the most amazing collection of indoor plants in the classroom and she tended to them daily and I was lucky enough to sit kind of in that corner and to me, that was- that was the coolest thing in the world."
Middle school	Nature experiences through a middle school class	"Middle school had a pond on the property which was probably a storm water control pond or something. But it was natural and we'd go down there for science classes and do the typical sampling for amoebas and all that..."
High School	Nature experiences through a high school class	"I had a very eccentric art teacher and I guess he encouraged me to, you know, draw the- and paint the natural world, which was my inclination. You know, but he was very supportive of that."
College	Nature experiences through a college course	"So, they had a field station as part of the university so we'd go to like [name] and do, you know- like capture small mice or like, you know, go on owl hikes or whatever else we- all the kinds of things you do as an undergrad in ecological science major. Key out plants.

Post-college	Nature experiences through graduate school	"I got a phone call from one of my faculty members in horticulture that said we have this graduate assistantship and do you want it? You need to start next week. So, I went back to school and got a master's degree in horticulture so then I had more of the hard sciences in it. But at the same time, that's when I was taking- always taking pottery and art classes and I realized I could merge the two…I got to do my first environmental art piece and it was adobe and branches. And so, you know, that- when I realized that, like oh my god, I could do art and landscape architecture and all this stuff like all together..."
Independent outdoor time	**Outdoor time that is characterized by independent, self-directed activities without adult supervision, e.g. free outdoor play, fort building, drawing or bicycling with friends**	"I was drawn towards a lot of like the little pockets of green. Be it like climbing that one tree that's on the block or digging around in the dirt with like figurine toys just because we didn't necessarily have like a doll house or something bought for us. So, it was that sort of improvisation. Like okay, I need something to play with and this I'm drawn towards. I don't know why not like car, you know what I mean, or like blocks or something like that. But yeah, it was definitely green spaces to play on or with or add to whatever toys we had."

After reviewing the life history codes as a team and testing for interrater reliability (Cohen's $\kappa = 0.75$), we began to layer in our interest development coding scheme, which also had several iterations. We developed robust criteria for identifying interest type and coded for either situational or individual interest for each excerpt (Table 3) where a nature-based experience, whether out-of-school, independent outdoor time, or school experience, was described by the interview participant. We defined situational interest as primarily being supported by an environment with structural support, while individual interest was primarily self-initiated as evidenced by such phrases as: "I did that on my own"; "I was drawn towards"; "I got really into"; "there was a curiosity"; "I had this big interest"; "I cofounded…"; and sometimes included activities with others, such as: "Then as I got older, we kind of pushed further into the woods." We completed some pilot coding of the finer scale of all four phases of interest development and confirmed the inappropriateness of using this approach at this grain size. Our interest development coding included excerpts from all 18 interviews. We thoroughly reviewed all of the interest development excerpts as a team, resolved differences in coding, and completed a test for interrater reliability (Cohen's $\kappa = 0.93$).

Table 3. Code descriptions for situational and individual interest with example excerpts.

Interest type	Code description	Illustrative example excerpts
Situational	Primarily supported by environment that has structural support, including institutions, family, mentor, etc. May include independent activities when they rely on supports, such as independent outdoor time play, that is encouraged by parents.	"I remember a summer I did a week or two-week long art camp where there was a lot of interaction there with nature." "Well we were there with Boy Scouts, you know, so there were other fathers around, there were lots of other kids around. It was a group activity. It wasn't like the way I like to go camping now is, you know, get out in the woods and be alone and that wasn't what this was about. This was get out in the woods and sort of rough it." "We live right next to the woods and I went back there as an older person but it was- it's scrappy woods. You know, the teeny, tiny patch but it had grape vines all over the place because it was scrappy woods, and so we were able to play in that."
Individual	Primarily led by individual; self-initiated; characterized by examples of actual or exhibited curiosity questions, experimentation, investigation or other naturalist practices. Also, marked by persistent or repeated engagement, as with books or other content. May still have some environmental support, but individual choice is dominant.	"I got really into bats in high schools, and actually…I built a bunch of bat houses…I built like 30 of them or something like that." "I actually did a fair amount of fishing with the kid who lived on the street. (I) actually remember thinking why are these fish eating? Why is this area of the lake filled with weeds? All that. So, like there was a curiosity there." "I became fixated with trying to capture nature in certain aspects…make nature more visible or natural processes more visible. So that was something that, for certain, all of my work was within that conceptual kind of field. That became a real fixation for me for sure."

Coding for examples of situational or individual interest allowed us to explore how participants' exposure to nature across multiple facets of their particular learning ecology may have supported their interest development. It also revealed the transitions between well supported situational interest and more focused, persistent individual interest. We coded for these recognizable transitions between phases and found 49 examples of these transitions distributed through 15 of the 18 interviews.

To more closely identify patterns in the data, we created three matrices that examined the frequency of code applications (Miles, Huberman, & Saldaña, 2014). The matrices included (a) the type of nature-based experiences (e.g., independent outdoor time), (b) the correspondence of situational or individual interest with these types of experiences, and (c) the distribution of interest types across different stages of life (e.g., early childhood, middle childhood, adolescence, and young adulthood). We then used these frequency matrices to consider what types of experiences were associated with supporting situational or individual interest development at different ages for this group of naturalists.

3.4 Findings

3.4.1 Participant characteristics

All participants completed high school; 16 went to public high school and two attended private or parochial schools. All of the participants had some college exposure; 15 received a college degree and the remaining three attended some college. Of those with a college degree, six received a Bachelor of Science (Biology, Ecology, and Evolution, Engineering, and Computer

Science), four received a Bachelor of Arts (Biology, Environmental Science, and Social Studies), and five received a Bachelor of Fine Arts (Art and Design).

Over half of the participants went on to graduate studies. Of those entering graduate school, six completed a Master's of Science (Conservation Biology, Forestry, Ecology, Horticulture, and Political Geography), three completed a Master's of Arts (Art, Art Business, and Landscape Architecture), and one did not complete the degree they began (Environmental Engineering). Of the total number of participants, three completed a Ph.D. (Genetics, Avian Ecology, Political Geography). Fifteen of the participants are engaged in naturalist practices professionally. Professional scientists who either conduct research and/or are engaged in natural resource management account for six of those who use naturalist practices professionally. The remaining nine participants who are engaged in naturalist practices professionally are educators who bring the natural world into their work either through science (five) or art (four). The three participants that are not engaged in naturalist practices professionally are serious amateur naturalists who are consistently and deeply engaged in birding, botany, and/or environmental advocacy for natural systems. Fifteen of the participants were currently employed, two were retired, and one was unemployed at the time of the interview.

All of the participants currently live in the Pittsburgh region; however, they did not all grow up in the region. There was a fairly even distribution in the type of community they primarily grew up in: 6 are from rural communities, seven from urban communities, and five from suburban communities. The places they grew up in were broadly dispersed throughout the continental United States and included the urban core and suburbs of Pittsburgh, other large cities in the Midwest and West Coast, and rural communities in the Northeast and Southeast. However, several of the participants discussed moving from one type of community to another during childhood. There were also several participants who recalled spending memorable periods in rural areas with relatives even if their primary residence was suburban or urban.

3.4.2 Interest in nature develops across the learning ecology

Participants nearly universally attributed their initiate interest in nature to independent outdoor time saying things such as, “I can remember having a lot of freedom to go and explore the neighborhood.” The perception that early independent outdoor time was formative for their later interest in nature held for people in their 20s, in their 60s, and all ages in between; it was remarked on regardless of whether they grew up in inner cities, suburbs, or rural communities.

The kinds of independent outdoor experiences that participants recalled often involved nearby places they could easily access as young children, such as small woodlots, vacant lots, or back yards. Trees figured prominently in participants’ recollections, with frequent mentions of playing and climbing in trees in yards, on the block, or in nearby woodlots. Some participants connected basic outdoor play, such as imaginative games, to their adult interest in nature, whereas others described strong, early connections with specific natural elements, such as water, insects, or birds, as in this recollection from a retired, serious amateur naturalist:

> *There was an empty lot at that intersection and I lived a block away and a couple of things impressed me. I would go to that spot and sit in what I considered the woods. Now the traffic is all around, but I felt safe…I really felt very safe there and sat there and looked at things. I would look at leaves and, you know, the whole bit. I looked at everything…There were trees and probably brambles and whatever grows on an empty lot…in those days*

common nighthawks were common and there was an apartment building the next lot over on [street name], that had a gravel roof and every early May, the nighthawks would return and dive bomb over that roof. Lots of them! And I could sit on the front stoop of my house and watch them, and I thought they were awesome. They were like my signature bird.

However, independent outdoor time was not the only place that participants perceived their connection to nature developing and being sustained. We found that all participants recollected nature-based experiences across their learning ecologies, including in school experiences and out-of-school experiences, in addition to independent outdoor time. Still, school-based nature experiences, which were distributed throughout the elementary, middle, and high school accounted for less than one-quarter of all the recollected nature experiences. Although some participants had powerful school experiences with nature, many others could not recall a single school experience that connected to nature at all. In contrast, over three-quarters of all the nature-based experiences that participants perceived as significant happened during structured out-of-school activities or as unstructured independent outdoor time.

Many participants perceived out-of-school experiences as being important supports for their on-going interest development in nature; the most dominant recollection among these participants were family led experiences, such as hiking or fishing, followed closely by informal programs, such as scouting. Participants typically perceived the combination of these types of activities—across the learning ecology and throughout their childhood—as critical for their on-going and lasting interest development in nature. When asked to recall a specific moment that led to their interest development, most participants instead pushed back and expressed the idea that their interest was instead attributable to a host of interwoven experiences. They used phrases like "constant exposure" and "it's just what we did," and explained that they believed that experiences across multiple settings came together to help grow and maintain their interest in nature.

3.4.3 Episodes of situational and individual interest are nonlinear and mutually reinforcing

We found that all 18 participants described instances of both situational and individual interest occurring throughout their learning ecology and at all stages of their childhoods. They largely described a nonlinear, back and forth layering of situational and individual interest experiences, rather than a clear sequence of situational interest followed by individual interest. In many cases, individual interest was strengthened due to additional situational interest experiences that provided structural support in the way of programs and important adults. In all cases, the types of interest recalled by the participants were intertwined in both time (different stages of childhood) and space (different elements of the learning ecology).

Out-of-school nature experiences, both structured and semi-structured, made up the majority of the examples of situational interest that were described by participants. This included activities, such as projects in afterschool environmental clubs, family visits to nature centers, and watching nature programs on television. Individual interest episodes were recollected as most often having occurred during independent outdoor time experiences. Although school-based experiences were overall less indicative of interest development than either out-of-school or independent outdoor time, these experiences were nonetheless described as important for participants in their recollection of experiences that supported the development of their individual interest. Several participants recalled teachers or classroom activities that anchored their burgeoning interest.

Participants recalled examples of situational interest as occurring most often between the ages of 6 and 12 years for both out-of-school and independent outdoor time. Examples of out-of-school time experiences where situational interest were recalled include such things as camping and hiking with the Boy or Girl Scouts, fishing with parents, and family visits to museums, especially natural history museums. Independent outdoor time experiences that participants recalled typically involved exploration of nearby woodlots and parks due to a parent's encouragement or insistence to get out of the house to play. One participant remembered their experience this way: “They wanted to see me go outside. Whenever it gets dark, come inside.”

Participants recalled that middle childhood, between 6 and 12 years old, was also when the most examples of individual interest during independent outdoor time occurred. Some described the value of this independent outdoor time during adolescence for individual interest development. Independent outdoor experiences at this stage often included recollections of close examination of the natural world through activities, such as bird watching, experimenting with building using natural materials, or insect collecting, as with this recollection, “We did a lot of collecting of insects too … My brother and I used to chase butterflies all over the neighborhood.”

Individual interest during out-of-school activities was more broadly distributed throughout the developmental stages and included recollected instances where participants described their motivation to pursue a topic or experience on their own, such as requesting to participate in a program. School provided over a third of the individual interest according to our participants' recollections and these experiences tended to happen in high school, college, and beyond. Participants often drew connections between their in- and out-of-school experiences as well as episodes of situational and individual interest connection across the learning ecology. Here, a participant recalls a high school horticulture class that led to an individual interest episode at home where she was able to continue her exploration of plant propagation.

Horticulture was cool because it was hands on and I liked to learn hands on. That's what I connected to most. And it was fascinating to me to learn about something and then have a lab like plant propagation where we got to touch the plants and propagate them and I got to bring them home and take care of them.

3.4.4 Pathways may vary but structural supports and mentors are consistent

We now present three individual cases to explore more of the details of how individual and situational interest manifest and transition across the learning ecology, with an attention to who is involved and how structural supports, situational interest, and individual interest intersect. The three cases—an amateur naturalist, an environmental educator, and an ecologist—were chosen to reflect the diversity of our participants across age, gender, race, and naturalist identity. Their varied life paths toward becoming naturalists help to reflect the breadth of experiences that our 18 participants recollected and shared with us. The cases illustrate how interest in nature and a naturalist identity can develop in very different types of learning ecologies. For some, strong supports at both school and home have led to professional work with nature, for others negative experiences in school were overcome, thanks to family encouragement or, sometimes, there was support of a critical adult outside of the family. In each of these three cases, we see how participants perceive the importance of structural supports, such as mentors, for the development of their adult naturalist identities (Table 4).

Table 4. Examples of situational and individual interest development in nature drawn from participants' recollections and descriptions in each of three focal life histories

	Eric: The serious amateur naturalist	Ada: The environmental educator	David: The ecologist
Participant characteristics	65-year-old African American man Facilities coordinator for large corporate office 2 years of college, Biology, no degree	33-year-old Latinx woman School garden coordinator for urban community non-profit BA in Biology & Fine Art; MS in Ecology	41-year-old white man Conservation planner at statewide environmental organization BS in Ecology & Evolution; MS in Conservation Biology
Perceived structural support for situational interest	Parental support through gardening, enrollment in out of school programs and exposure to books, such as field guides Frequent activities with and encouragement from grandmother Museum educator recognized interest and supported additional learning opportunities	Regular outdoor activities with mother, such as fishing Positive experience with scouting and scout leader Pivotal support from high school teacher as mentor and advocate	Regular outdoor activities with both parents, such as fishing and visits to nature centers. Strong school-based experiences throughout K-16 including field studies and leaf collection Out-of-school experiences such as clubs and nature themed media (e.g. books, videos)
Recollected examples of individual interest	Insect and spider collections Nature drawings and photography Exploration of city parks and greenspaces	Riding horses in middle school and beyond Self-advocacy for advanced science studies in high school Powerful experience living off-grid as young adult	Fishing and camping without adults Building bat boxes in high school Creating environmental film company
Articulated challenges for interest development	Discouraging high school experience Inability to complete higher education	Negative feedback from some school officials Contrasting parental attitudes towards nature	Nothing acute

3.4.4.1 The serious amateur naturalist

Eric, 66-years-old and African American, works as the facilities coordinator in the office of a large, multinational corporation. Eric is a serious and long-time amateur naturalist whose story illustrates how early and consistent family encouragement supported his situational interest in nature. His story also offers some cautionary examples of how a lack of support, and even discouragement, in formal school settings undermined his potential trajectory toward a more academic connection to science and nature. However, despite the lack of strong support in school, Eric's story provides an example of how individual interest can develop through a long-term relationship with an out-of-school program that provided a strong platform for knowledge development and interest persistence. Although he does not engage in naturalist practices professionally, he is a serious amateur naturalist with an emphasis on botany and photography. He selected the categories of serious amateur naturalist, community garden manager, and environmental artist to describe himself.

Eric recalled that his desire to explore outdoors and seek out the beauty in nearby nature was strongly encouraged by his family from early childhood. Both of his parents and his grandmother played significant roles in helping to provide structure for situational interest to develop in science and nature. His family was of modest means—his father was a minister and his mother stayed home with the children when they were young and then went on to work in a department store when Eric was in junior high school. Although neither did something that professionally connected them with nature, Eric remembers that they both loved to be outdoors.

Eric recalled his interest developing through such experiences as roaming the woods, gardening and picnicking with the family throughout childhood. Eric attributed his parents' affinity with nature to their having grown up together in a small, rural community that was near the Mid-

Atlantic city they moved to before his birth. After the move, the family continued to regularly visit his grandmother in this nearby rural community and he reflected, “a lot of my interest was really spurred by her and by where she lived.” He attributed a lot of his interest development to his grandmother and recalled spending extended periods with her during the summers and hours spent in her garden, which is the site of his earliest memory. He also recalled his grandmother taking him foraging for wild edibles, including mushrooms. These examples of situational interest were formative in his perception of his own interest development.

His father had an interest in photography, which Eric took up as well. He recalled bringing an old box camera to his grandmother’s house and roaming the fields looking for things to photograph, an early example of Eric’s individual interest beginning to emerge. These linked interests—nature and photography—persisted throughout Eric’s adult life and he continues to photograph plants and insects regularly.

When at home in the city, Eric recalled that his parents gave him a lot of freedom to be outdoors without adult supervision. He described how he played outdoors in green spaces near his home and the small garden in their yard that his father maintained. Eric also credits his parents in helping to maintain his growing interest by buying books and bringing Eric to the local museum of natural history. Eric perceived that he had a strong interest in nature as early as 10 or 11 years, which he remembers expressing through individual interest activities, such as collecting insects and spiders, which his mother would let him bring inside in jars.

Eric cited his father as having recognized his growing interest and enrolled Eric in a “junior naturalist” program at the local natural history museum as a pre-teen. Eric remembers attending the program, which was free at the time, every Saturday for several years. He convinced a couple of neighborhood friends to attend with him and together they studied at the museum and went on field trips to a nearby university field research station and to state parks. He recalled with pride winning second place in a diorama contest where he constructed a diorama of preserved insects and plants at the age of 12; the first-place winner was 16 years old. One of the program instructors recognized Eric's interest in insects and recommended that he study more closely with the museum's entomology department, where he ended up taking additional classes to learn more specifically about insects. This provides an example of structural support from the museum staff in providing a platform for Eric's individual interest to grow.

However, Eric did not recall finding support for his interest in nature in school. In fact, when asked to consider examples of school experiences with nature, he could only recall a negative experience that took place in 11th grade. He recalled going to live with his grandmother for a year and a half and attending school in the rural community she lived in.

> *I remember I wanted to do a biodiversity study and I still have the papers with me— my own drawings. I was doing a study of the mud dauber wasp and its influence on its immediate ecosystem. The mud dauber was a wasp that preys on spiders and literally entombs them in these mud sills and I was attempting to do a biodiversity study and I showed this to one of my teachers but it didn't have the impact that I wanted it to. I didn't get much feedback from that teacher. It was a little disappointing because at the time, I thought it was certainly worthwhile and wanted some pointers on how to improve this study as best as possible…I think if I had gotten a bit more help, a bit more direction, it would've had a better influence on my track after that.*

This project, and the attending lack of support, clearly held some significance for Eric based on his tone when telling this story and the fact that he maintained papers from the project for approximately 50 years. Despite the lack of support from formal school experiences, however, Eric remembered continuing to develop his individual interest in nature. He said of this period "Everything fascinated me! Every living thing fascinated me."

Eric spent 2 years studying biology in college but did not have the money to complete his degree. As an adult, Eric recalls spending many years working in urban community gardens, exploring and photographing plants in a large urban park, and continuing to learn about natural history through informal walks and clubs. He enthusiastically described an independent inventory of the plants and insects in a large vacant lot near his home that he is currently engaged in. The lot is a block long and half a block wide and offers Eric a chance to wed his interests in photography and nature through this photographic study. When asked why he would take up such study, he described his interest this way:

> *I'm always astounded at the beauty you find in the oddest places, and in the diversity of life in places like that, that you ordinarily would not think would have very much life. In looking at it, it looks like a waste place, an abandoned plot and going in and taking time to look here and there and to look closely—there's wonderful things you can find.*

Eric attributed this long-term persistent interest in nature, particularly this kind of nearby nature, as coming from two primary early sources: his family, especially his grandmother, and his long-term experience with the natural history museum.

3.4.4.2 The environmental educator

Ada, 33-years-old and Latinx, is the school garden coordinator for a nonprofit organization that specializes in supporting urban agriculture. Ada attributed much of her adult interest in nature to experiences with her mother and with the Girl Scouts. She experienced differing attitudes toward nature in the home—positive from her mother, negative from her father—which provided an interesting example of how positive situational interest experiences, coupled with the early development of individual interest, can buffer negative input for some. Ada's story also illustrates the importance of adult mentorship and advocacy for her developing interest in the environment. Latinos are underrepresented in the sciences, including environmental science. Ada recalls struggling with science in school and credits a high school teacher as supporting her pathway to science. She ended up receiving her Bachelors in both Biology and Fine Art and a Masters in Ecology. She selected the categories of environmental educator, community garden manager, and environmental artist to describe herself.

Ada moved several times throughout childhood because of her father's work, but grew up primarily in large cities. She recalls being attracted to pockets of green and climbing trees on her block at a very young age. She frequently played out of doors, improvising games and transforming toys, such as doll figurines, into tools to dig in whatever dirt she could find.

Her parents' contrasting relationships with nature offered very different perspectives for Ada. Her mother was the daughter of an Eastern European immigrant and grew up hunting. Ada recalled ample opportunities that her mother provided for her situational interest in nature to grow. Her mother frequently took Ada to the park for walks and went fishing with Ada. In addition, her mother had studied microbiology and modeled an interest in science for Ada. Her father, who immigrated to the United States from a Latin American Caribbean island, had more negative attitudes toward outdoor recreation, which Ada attributed to a cultural "big stigma" wherein he associated getting dirty and playing outdoors with poor people. When Ada went camping for one of the first times with friends in high school, she described her father's reaction this way: "He's like, why would you want to go camping? Like we came to this country to sleep on a mattress! Why would you want to sleep on the ground?”

Ada reflected that her father’s discomfort with spending time outdoors was also related to his sense of not belonging. She recalled an attempt by her mother to take the whole family hiking, which turned “disastrous,” in part, because of her father’s distrust and discomfort of “not seeing anybody else like us around there.” The tension that Ada perceived between her parents’ orientations toward nature was not absolute, however. She recalled that her father shared her interest in horseback riding, which she did throughout childhood and which served as common ground for spending time with her father outdoors. Ada perceived her mother as the stronger positive influence on her interest in nature and articulated that her father’s discomfort did not outweigh this.

Ada also had a short, but memorable experience as a Girl Scout. Although she only participated in the Scouts for about a year in elementary school, she had a strong association with the scout leader and vivid recall of activities, such as building forts, making fires, and hiking with the troop. When asked about the development of her interest in nature during her middle childhood years, she said, “I can categorically tell you it was from Girl Scouts.”

Ada did not recall in-school experiences that supported her interest in nature until high school. She described a transition period from situational to individual interest happening during high school with the support of a key mentor, Ms. Z., who was Ada’s homeroom teacher. Ms. Z. was a Biology and Advanced Placement Environmental Science teacher and Ada heard Ms. Z. talking about the class, which excited her. Ada remembers liking science classes beginning in elementary school, enjoying how the classes could help explain questions she had about the world around her. This interest continued into high school, where she took biology and did well. She also found that her interest in art dovetailed with interest in science, helping her to draw, for example, anatomical figures more accurately. However, Ada was not in any advanced classes and recalls being initially discouraged from taking the Advanced Placement Environmental Science class by her advisor. However, by this time she had a strong individual interest in nature and she persisted.

> *Well, what happened was I was discouraged from taking the class because I was not in any advanced classes…but I like science…and if I fail, then I fail. But at least I get to learn something…And I remember talking to Ms. Z about it because she was very excited. She was like 'Oh yeah, yeah, take the class! This is when we're gonna have it next semester' and then I remember my advisor saying that. I was like, well I'm gonna take it anyway because I was just a stubborn kid…But Mrs. Z wrote me a note and said Ada can be in this class, and I did not get good grades in it but I learned—I still learned how to make quadrant studies, I still learned how to identify plants, I still learned what acid mine drainage is, and that, I think, alone sparked the interest…I changed what I thought I was going to do…I thought I was going to be just like a teacher. I honestly did not even choose a college until my last semester of my last year of high school. I had no clue. But with that, I started thinking about science. I started thinking about the outdoors and that at least I really like it out here. It's interesting to me, instead of school being just like 'oh I have to do this.'*

Ada went on to study both Biology and Art as an undergraduate, taking 6 years to complete her degree. Ada's identified her interest in nature making the final transition to individual interest when she spent several months doing an ecological footprint study off-the-grid in a New England state. During the program, she found peer mentors, particularly another young woman in the program, who supported her learning process. She describes this period as when she was able to overcome her fears of being out in nature—at night, with creatures—and described how she emerged with feelings of respect instead. She described her realization this way, “there was more of a respect for it [nature]. So, like I can’t see everything but that’s okay. I’m not supposed to know everything. I’m part of this. I’m not higher than this or bigger than this.”

Ada reflected that her interest in nature translated into a series of environmental education jobs as an adult, including her current job that focuses on urban gardening with youth. She described how food and nature have been connected throughout her life and linked her current work as farmer educator and beekeeper both to memories of visits to her father's country of origin in which she recalled seeing people climb trees to pick fresh fruit and also to her role as the manager of food and waste during her experience in New England.

3.4.4.3 The ecologist

David, 41-years-old and White, is the conservation planning manager for a large, statewide, environmental nonprofit. David described a childhood rich with experiences across the learning ecology that supported his developing interest in nature. David’s story also includes examples of varied interests and how he brought these disparate interests together. He recalled family activities and positive in-school and out-of-school experiences that together provided a strong foundation for his professional work with nature. His robust set of opportunities and interest development led David to receive a Bachelor of Science in Ecology and Evolution and a Masters in Conservation Biology. He selected the categories of both research and applied scientist to describe himself.

David moved to a rural area at the age of 4 and recalled being given a lot of freedom by his parents to be outside in an unstructured and unsupervised way, either alone or with friends. These earliest experiences are an example of the situational interest that David perceived his parents supporting through their encouragement of his interaction with nature. Although their careers were not connected to the environment or nature—his mother was a banker and his father was an electrician—they both showed an avocational interest in nature. His mother took the family hiking occasionally and the family went to state parks and nature centers several times a year, often for educational events, such as a raptor demonstration. David recalled fishing regularly with his father. They would also spend time exploring a lake that was nearby to their house looking for beaver lodges. His father, who had some general interest in birds, would bring binoculars.

> *…one time we went back there and…through the woods at the end of the wetland and there was a gigantic, white bird. You know…in the wetland and just like—we were both kind of blown away by it and we're like trying to figure out what it was and like we watched it for a while. I remember going back home and I guess we had that Reader's Digest North American Wildlife … I remember going home and looking through that and finding out like "oh it was a great egret"*

In this example, David's exposure to nature moves from situational interest, where his father provides the dominant environmental support, to individual interest, where his curiosity propels him to seek out information on his own.

David remarked that there was a strong science program in his school district. In upper elementary school, he was encouraged to do a leaf-collection, a classic naturalist activity, which he described as "really exciting." In middle school, teachers used the school campus to have students collect data, such as water quality samples. David also recalled being engaged in some structured out-of-school experiences, including a brief experience with scouting in elementary school and robust participation in afterschool science clubs and competitions in high school.

David also described the impact of media on his interest development. There was one particularly potent experience, which involved watching a video on the Galapagos Islands in a middle school class that David recalls as a very inspirational moment. This provides an example of a transition of his interest in nature from situational to individual interest.

> *We watched a documentary about the Galapagos and it just like blew my mind. It felt like it was something new that was just discovered even though, you know…Galapagos has been known about for a long time before that, but you know…just the way they presented it was like there's something out there to be discovered…they talked about a number of species and they talked about Darwin's finches and other bird species and the adaptations and you know, kind of how they had never—the documentary probably played up all these species that have never encountered people before, so they had no fear. It was just like super, super inspiring.*

David's interest in nature was not exclusive. From an early age, he describes building and engineering as interests. He recalls working alongside his father, who was an electrical contractor, as being essential to his sense of self as a child, saying that "I had this big interest in engineering and more technical things." As a teenager, he built bat boxes, which connected his twin interests in building and nature. He also described a very robust individual interest in film-making throughout high school, during which time he created a film company with friends and made some documentary films about teen issues.

David began college as a film major intending to make nature videos, another example of his efforts to connect two primary individual interests. However, in his third year of college he transferred his major to Ecology and Evolution after experiencing a science class that he perceived as changing his perspective of what science could be.

> *…after I got on to the core classes, I kind of had the idea I should really go and take an ecology class and Plant Ecology was offered…like the first week of class, I was like just completely hooked on it and everything…Just part of a relation to science is an active thing…I had a feeling that, you know, we had everything figured out…but I didn't really fully comprehend that there's active research going on…that there's still stuff to figure out…I guess I had thought we had figured out biology and stuff like that…the frontiers that everyone was talking about of discovery were space, were physics or stuff like that…but once I kind of realized that like there's a lot we don't understand about really simple stuff, you know, that kind of made it even more exciting.*

David's individual interest solidified as he moved into adulthood, which was apparent by his self-initiation of nature-based inquiry activities and persistence with those activities. For example, after hearing about an opportunity to work at an ecological field station, David recounted that he sought out the professor who managed this program and ended up working with him for 2 years in college. He continued his studies of ecology, post college, through an internship with an environmental government agency and then went on to receive a master's degree in Conservation Biology. His deep and persistent interest in nature is evident today in his professional work as an ecologist and conservation planner.

3.5 Discussion

Analysis of these life history interviews reveals that for these 18 adult naturalists, elements across the learning ecology worked in concert to support interest development. Our use of participant recounted life histories may include some bias due to inevitable inconsistencies in individual memory and perspectives. However, the life histories also offer a unique window into how an adult who has made a lifelong commitment to the study and engagement of nature perceives the elements along their pathway that supported their interest.

For these 18 participants, persistent exposure to nature, across the learning ecology and throughout their childhoods, was critical for their long-term commitment to engagement with nature. Independent outdoor time was ubiquitous among these 18 participants across age, gender, race, type of childhood community, and naturalist identity. Early childhood exploratory play (Ainley & Ainley, 2015; Bulunuz & Jarret, 2015) and conversation (Ainley & Ainley, 2015) are key components of interest development, especially for developing science interest. There are numerous examples of successful scientists and Nobel Laureates including the entomologist and naturalist E. O. Wilson and the physicist Richard Feynman, citing early childhood play as key for their interest development (Bulunuz & Jarret, 2015). Direct experiences with nature through childhood play has been shown to be a common and important feature of early childhood experiences for adults who remain engaged with nature (Charles, 2009; Chawla, 2007; James et al., 2010; Prévot, Clayton, & Mathevet, 2016).

We found that frequent exposure to nature was typically coupled with strong structural support from mentors, such as family members and other significant adults. Adult recognition of emerging youth interest (Heddy & Sinatra, 2017) and the active brokering of additional learning activities are key components for youth interest development (Bell et al., 2013). Family members modeling interest and providing encouragement have been shown to be factors for early science interest development (Dabney, Chakraverty, & Tai, 2013). For some of these 18 participants, adult support came in school, as with Ada's high school teacher advocating for her to take Advanced Placement Environmental Science; for others, the support came from out-of-school settings, as with Eric's family encouraging him to explore nature independently and participate in programs at the local museum of natural history. Ada and Eric's recollections are emblematic of instances recounted throughout the 18 interviews, which highlighted how consistent family support and/or ephemeral support from perceptive nonfamilial adults played critical roles for interest development.

The 18 participants recollected situational and individual interest episodes throughout childhood and described these episodes as occurring in a nonlinear, layered sequence. The Hidi and Renninger (2006) four-phase model of interest development's use of finer grain categories within situational (triggered and maintained) and individual (emerging and well-developed) interest were not useful in this analysis of interest development over the longer timescale used in life history interviews. The model's frame as a linear, sequential building of interest also was not reflected in these life history data. Although situational interest was more prevalent between the ages of 6 and 12, there were numerous examples within participant recollections where we saw a nonlinear path from situational interest to individual interest to situational interest again. David's experiences in upper elementary and middle school, for example, show several of these concurrences, which suggests a fluidity between situational and individual interest over the course of a lifetime that is not currently accounted for in the model. Articulating the potential for overlapping situational and individual interest would be a useful addition to the model when it is being applied to interest development at a long timescale, such as a life history.

However, the application of the model using the grain size of situational and individual interest was useful in understanding the broader type of interest being experienced across the life history. Experiences that are indicative of situational versus individual interest include different amounts of external, environmental supports, internal drive, and curiosity to persist with engagement. As described by Hidi and Renninger (2006), the situational interest that typically relies on external supports is sparked by something in the environment and is more fleeting, and may or may not persist over time. In contrast, individual interest is typically self-generated, wherein the individual begins to generate curiosity questions and show resourcefulness in efforts to gain additional knowledge, including persistence in the face of challenges. For these 18 participants, encouragement and external support was still of value during phases of individual interest development.

Our analysis of these 18 life histories suggests that while situational and individual interest episodes occur throughout the learning ecology, they do not occur at the same volume in different settings. For example, situational interest was more likely to be seen in out-of-school experiences, as in Eric's mushroom walks with his grandmother. From these cases, it appears that the strength of these out-of-school experiences may be in supporting situational interest. For these 18 participants, out-of-school programmatic experiences did not appear to provide them as many opportunities to develop an individual interest as other aspects of the learning ecology. Instead, we heard participants more often recollect individual interest episodes as occurring during school and independent outdoor time.

Reflecting Azevedo's (2011) notion of interest as lines of practice, the life histories also reveal how the intersection of different interests supports the development of deep individual interest and a naturalist identity. In Azevedo's account, the object of interest should not be thought of as a particular content area, such as nature, but instead as a set of interrelated activities. In all three of our cases, as well as other participant recollections, we saw examples of how participants wove together interests, such as photography, art, and building into their interest in nature. These intersections helped support increased knowledge of and value for nature in the participants' experience. They used these interests to improve observation of natural phenomena, such as the drawing that Ada did of anatomy, as well as to support their interest in stewardship of the natural world, such as with David's construction of backyard bat boxes. Interests develop best when those activities overlap in ways that allow people to be successful and to connect and express other skills, knowledge, and identities that are important to them. We saw many examples of this convergence in our data.

The overlapping and interweaving of both lines of practice and episodes of situational and individual interest can be considered together as a reflection of the deeply layered ways that people develop the kind of lifelong interest in nature that these 18 participants express. Taken together, these layered patterns of lines of practice and situational and individual interest development are important for out-of-school educators to consider. Specifically, we identify two important questions for science educators, especially those in informal settings, such as our partner museum that is working to support the development of 21st century naturalists: How can programs provide an opportunity for children to experience some semblance of independent outdoor time if they are not afforded this by their families? And, how can informal programs provide structural support and mentorship to youth participants in ways that both trigger situational interest, but also extend to supporting individual interest development? These questions are less salient where there are other opportunities in the learning ecology to grow individual interest. But for those youth that may not have as many opportunities or strong structural supports to engage with nature, informal education programs have an important role to play in providing more than just exposure. They might consider the ways in which they can design their programs to go beyond merely sparking interest and toward supporting the development of lifelong interest in science and nature by providing strong adult mentors and experiences that foster individual interest development.

4.0 PAPER 3: TRANSFORMING ENVIRONMENTAL INTEREST INTO IDENTITY THROUGH RELATIONAL PROCESSES BETWEEN PEOPLE AND PLACE

4.1 Abstract

This paper explores a transitional moment for youth who are developing their nascent environmental interest into a deeper, individual interest that includes envisioning their future selves as environmental people. Developing a deep interest in the environment and ultimately adopting an environmental identity is important not just for STEM careers, but also for developing science literacy and for using science to help change our communities. I use a nested case study approach to explore how one informal science program supported environmental interest and identity formation. Using ecological thinking that draws on indigenous, post-humanist, and new materialist philosophies, I aimed to shift my gaze from individual youth experiences and towards relational processes. Using participant observations, interviews, and artifact analysis, I identified three infrastructural program elements that contributed to this deepening environmental interest development, each of which builds on the role of relational processes between and among youth, educators, and local elements of the nonhuman natural world. These included 1) fostering youth connection with nonhuman nature through physical contact with creatures that once scared or disinterested them; 2) positioning youth as effective agents in the care of land and waters; and 3) providing meaningful examples of possible future selves as environmental people. I describe youth, educators, and nonhuman nature working together iteratively and reciprocally to support the co-construction of interest development.

4.2 Introduction

This paper explores a transitional moment for youth who are developing their nascent environmental interest into a deeper, individual interest that includes envisioning their future selves as environmental people. I conducted a case study of an adolescent environmental summer program held in an urban park in order to examine the role of informal science programs as critical ecosystem actors positioned to aid in this transitionary moment. By looking at program infrastructures, I aim to better conceptualize the mechanisms within this informal program as a learning ecosystem unto itself. The program of study, called Youth Naturalists, employs naturalist skills and practices in support of youth interest development with an aim of helping youth identify and participate in future learning opportunities in science and the environment. The program reflects a deliberate effort by the educational organization to create an opportunity for youth whose previous program experiences had sparked their environmental interest and who wanted to deepen their interests and skills, be in community with others who share their affinity with the natural world, and develop their identity as environmental people.

4.2.1 Individual interest as catalyst for identity development

Informal science programs play an important role in the larger learning ecosystem of home, school, and out-of-school settings (National Research Council of the National Academies, 2015), particularly for adolescents who are able to initiate their own learning experiences (Barron, 2006; Crowley et al., 2015). Informal science programs have been shown to help spark youth interest (Hecht et al., 2019; Pinkard et al., 2017) and informal science educators can be valuable brokers helping to support youth as they move along pathways to related learning experiences within a learning ecosystem (Ching et al., 2016). However, the role of informal programs in learning ecosystems is often positioned as an introduction for sparking interest development (Hecht et al., 2019), even though triggering interest is just a first step in developing a persistent and individual interest (Hidi & Renninger, 2006). Pathway migrations through learning ecosystems often rely on learner interest, but youth in early stages of interest development may not be as likely to seek additional opportunities for learning as those with more developed interest (Renninger et al., 2015). Therefore, might informal science programs be designed to serve as more than just an onramp for interest and instead be designed to help deepen interest and to strengthen youth identity as environmental people (Azevedo, 2015; Van Horne & Bell, 2017)?

Developing a deep interest in the environment and ultimately adopting an environmental identity is important not just for STEM careers, but also for developing science literacy and for using science to help change our communities (Van Horne & Bell, 2017). Numerous scientific issues, from global climate change to local air quality, are environmental in nature. Urban landscapes can provide a critical opportunity to engage youth in local, place-based education that connects them to these issues, both in their immediate surroundings and in the larger world (Ardoin et al., 2013; Duhn et al., 2017; Greenwood, 2017; Smith & Sobel, 2010). Environmental activities that use the local landscape can help anchor developing interest in the places and issues that matter to youth (Schindel Dimick, 2016). Furthermore, knitting environmental education together with science education can provide a platform for youth to develop interest across the sciences, fostering the development of both scientific and environmental literacy (P.-Y. Lin & Schunn, 2016; Wals et al., 2014).

Interest is a critical element for promoting domain-based identity formation, such as thinking of oneself as a science or environmental person (B. D. Jones et al., 2015). Designing programmatic experiences that are interest-driven is important for learner engagement, which underpins the uptake of domain-based concepts (Azevedo, 2013). The progression from initial interest that is sparked by external forces to a well-developed and stable, self-initiated interest has been described as a movement from situational to individual interest (Hidi & Renninger, 2006).

But how well do we understand how learners move from initial interest to individual interest that will persist? Explorations of the dynamic and complex processes of interest development across different timescales and settings – that is across the learning ecosystem – are lacking in the literature (Azevedo, 2018). This paper is an effort to investigate this dynamism by zooming in at the program scale to examine a moment of transition for adolescents as they move towards individual interest and a growing environmental identity. I explore how one informal science program supported this transition by creating infrastructure to explore connections between youth and nonhuman nature, position youth as agents in the care of land and waters, and offer opportunities for youth to envision their future selves as environmental people. These mechanisms resulted from deliberate design choices made by educators to institute program infrastructures that supported a disciplinary identity formation as environmental people (Azevedo, 2015; Van Horne & Bell, 2017). Considering infrastructural design is an important component of developing and managing thriving learning ecosystems (Penuel et al., 2014).

4.2.2 Project overview

I used a nested case study approach (Yin, 2014) to explore how the Youth Naturalists program supported four of the adolescent program participants in this transitionary moment. I used a research-practice partnership approach for this study that prioritized equity and addressed the needs of myself as a doctoral student at the same time that it addressed the educators' needs

(Henrick, Cobb, Penuel, Jackson, & Clark, 2017; Penuel, 2017). The research-practice partnership project team included myself and environmental educators working with an urban parks organization. Our team maintained structured opportunities for collaboration throughout the process, beginning with monthly planning meetings over the course of six-months before data collection began in order to better understand practitioner problems of practice. We co-developed research questions and program activities that would support both learning objectives and data collection needs. Our reflective work together continued throughout program delivery and extended for more than six months after data collection was completed. This consistent and open process allowed me and my practitioner-partners to authentically work collaboratively to co-construct knowledge. Our research questions are:

1. How do relational processes between and among youth, educators, and nonhuman nature support youth environmental interest development?
2. What program infrastructures support these relational processes?

4.2.3 Conceptual framework

Informal education programs are critical actors in learning ecosystems (Banks et al., 2007). For this project, I zoom in to consider how learning ecosystems function at the program level. While learning ecosystems are often conceived as large scale, regional networks (Barron, 2006; National Research Council of the National Academies, 2015), I extend the definition of learning ecosystems to smaller scale elements, such as programs, by drawing on ecological understanding of the nested and multiscalar nature of ecosystems (Horton, 2018). Applying this understanding to learning ecosystems, I conceive of an individual program within a regional learning ecosystem as an ecosystem unto itself. I posit that regardless of scale, we can apply ecological thinking to consider learning ecosystem function by using relational processes as the unit of analysis (Code, 2006; Hecht & Crowley, 2020).

Specifically, I aim to explore how relational processes between human and nonhuman nature, including flora, fauna, land and waters, are central to environmental interest development. By relational processes I mean the interactions between and among youth, educators, and nonhuman nature working together iteratively and reciprocally to support the co-construction of interest development and learning (Hultman & Taguchi, 2010; Kawagley, 2006). This includes an embrace of the significance of physical place for learning (Tuck & McKenzie, 2015), not just as a backdrop, but as a chief component and animate constituent of learning ecosystems (Hecht & Crowley, 2020). My effort to use relational processes as my unit of analysis builds on previous efforts in sociocultural educational research to attend to the significance of both setting and relational processes between people for learning (Nasir & Cooks, 2009; Pinkard et al., 2017). I extend this work by including elements of nonhuman nature as central actors in the learning process (Bang & Marin, 2015).

My conceptual frame draws on indigenous philosophies that position knowledge and practice as interactive and contextual (Kawagley, 2006) and that challenge the nature-culture divide typically found in science curriculum in the United States (Bang & Marin, 2015; Bang et al., 2013; Medin, Ojalehto, Marin, & Bang, 2014). I integrate these with other feminist philosophies such as post-humanism (Haraway, 2016) and new materialism (Barad, 2007; Fox & Alldred, 2018) that position both humans and nonhumans as actors with agency that exist in relation to one another. These complementary philosophies, though emerging from different traditions and containing different nuances, both advance thinking around the mutually constitutive relationship between human and nonhuman elements of the natural world. I integrate both traditions in my conceptual framework in an effort to adopt an anti-colonial stance within my own educational research and to attend to the ways that emerging philosophies around human/nonhuman relations, such as new materialism, invoke concepts originally conceived in indigenous ways of thinking and knowing (Patel, 2015; Rosiek, Snyder, & Pratt, 2019).

My approach is designed to examine if and how the use of a learning ecosystem frame and relational processes as a unit of analysis might help reveal some of the complexity in the relationship between interest development and identity formation. In order to attend to nonhuman natural elements of the learning ecosystem, I blend traditional qualitative case study methods (Yin, 2014) with post-qualitative approaches that move beyond anthropocentric data collection and analysis to examine multispecies relationships that reveal the practices of and interactions between human and nonhuman actors in the learning ecosystem (Kohn, 2013; Krasny et al., 2015; Pacini-Ketchabaw, Taylor, & Blaise, 2016; Ruck & Mannion, 2019). In my conceptual model, I posit that these interactions between youth, educators, and place are iterative and reciprocal, forming a three-way fluid relationship where processes between any two of the elements are likely to also engage or impact the third remaining element (see Figure 1). The three-way nature of these relational processes relates directly to my practitioner partners' three ideal program outcomes which include youth environmental interest development, refinement of educator practice, and tangible improvements to the Park.

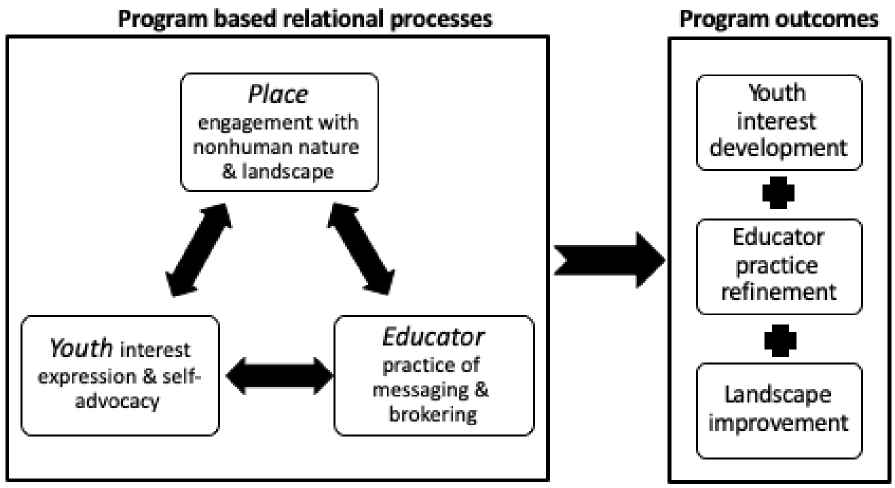

Figure 2. Conceptual model of relational processes between youth, educators, and place. These ideally lead to outcomes that include youth interest development, refined educator practices, and improved landscapes.

4.2.4 Project context

4.2.4.1 Landscape setting

The setting for learning is typically characterized using descriptions of program features and human participants. As part of my effort to embrace the significance of place and nonhuman nature for learning, I instead begin here by situating this work in the landscape. The primary setting for this study was a public park (Park) in a post-industrial mid-sized city in Appalachia. The Park was designed by landscape architects in the early 20th century with no interior roads for cars and this design approach had largely been maintained in the ensuing years as the Park continued to develop. Therefore, the Park had an interior wooded valley that was isolated from built aspects of the city, such as traffic sounds. Thanks to this, the Park was rich in flora and fauna and served as a popular site for urban naturalist activities such as birding, mushroom gathering, and botany walks.

The Park was composed of 644 hilly and heavily wooded acres made up of two distinct forest types depending on soil moisture and aspect: Dry Red Oak-Mixed Hardwood and Sugar Maple-Basswood. The dominant tree species include red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), red maple (*Acer rubra*), beech (*Fagus grandifolia*), tulip tree (*Liriodendron tulipifera*), and basswood (*Tilia Americana*).[2] The Park also contained three small streams that fed a major regional river. There were numerous shale rock exposures throughout the Park, especially along the cut banks of these streams, that made for engaging educational spaces to explore connections between land and waters. The Park was also home to a regional urban environmental center that offered educational programs for school children, campers, families, and adults. This facility served as the main gathering place for the focal program of study and its participants.

4.2.4.2 Program context and content

Our focal educational program was a five-week paid summer internship for adolescents offered by the Park organization. The program was developed specifically to support youth who had already expressed interest in science and the environment and who were primed to deepen this interest. In an effort to limit barriers to participation, all participating youth received an $800 stipend and basic outdoor gear including a pair of hiking boots, a water bottle, and t-shirts branded by the organization to wear during the work day. The program began with a 4-day retreat at an ecological research field station about 1.5 hours away from the Park. It then continued for four

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[2] I include Latin names throughout this paper in order to ensure clarity on the species, genus, or family I refer to. Note that 'sp.' indicates an example individual within a genus or family that has not been identified to species.

subsequent weeks from Monday through Thursday from 8:30am-3pm. Activities primarily took place in the Park, but also included field trips to other city parks and partner institutions, e.g., the regional museum of natural history.

During the program, youth engaged in closely-mentored learning experiences where they conducted ecological investigations, did environmental stewardship, and explored environmental careers. Youth were also introduced to naturalist and scientific tools. For example, the practice of using a naturalist field journal was introduced at the start of the summer; each youth was then given their own Rite-in-the-Rain brand weatherproof journal – a common tool used by professional ecologists – to use for the rest of the summer on a voluntary basis. Youth were also given open access to binoculars, magnifiers, and a wide variety of field guides to local flora and fauna that were available in a small library set up in the main room where the program began each morning. Educators also introduced youth to mobile technologies such as iNaturalist, an online, crowd-sourced platform where individuals can upload images for species identification, and Merlin, a mobile app used for bird identification based on basic visual markers such as size, shape, and color. These tools were used formally during the program in a limited way, typically just during the initial introduction to youth. Instead, they were made available for youth to use voluntarily at any time of their choosing.

The educators connected the educational activities with ecological work being performed by Park employees and scientists by using a theme of urban watersheds. This served as a frame for both the scientific inquiry and the stewardship that the youth did throughout the summer. The connection between land and water is what defines a watershed. When it rains on the land we live on, the water travels downhill and gathers itself together in a nearby stream, river, lake, or ocean. Making this land-water connection explicit was a central concept threaded throughout the program.

Poor water quality was a serious and persistent problem in the region. Over the years, the Park organization had invested considerable human and capital resources to help regional residents understand how the urban neighborhoods they lived in were critically connected to water quality, and how Park stewardship could play an important role in improving urban watershed health and water quality.

Watershed related program activities included weekly visits to a small stream in a nearby park undergoing watershed restoration where youth collected data on macroinvertebrates; sessions where the youth led stream investigations in the Park with younger campers; and stewardship activities designed to improve water quality, such as building a rain garden. Other activities included regular Park hikes where youth were exposed to identification strategies for different taxa, such as birds or trees, as well as one hike focused on observation and photography. There were also several activities led by environmental professionals that participated as guest educators.

4.2.4.3 Human participants

Project participants included youth, educators, and a university-based researcher. Participating educators (n=5) included the Park organization's director of education, the partnership coordinator, and three naturalist educators. Two of the naturalist educators – Taavi and Selah – were with the youth daily throughout the program. Taavi had studied environmental studies as an undergraduate; he had led this particular program for all five years of its existence and had considerable influence in shaping the program vision and approach. Selah had been a participant in the program as a high school student several years earlier; this was her second summer as a program educator. The third naturalist educator, Suzanne, lead the organization's internal staff training and participated in a few of the program activities.

I also consider myself, the university researcher and author on this paper who conducted the observations and interviews, as a project participant. At the time of the project, I had a master's degree in botany and was completing a Ph.D. degree in the learning sciences. I had also previously been both a classroom science teacher and informal environmental educator, including as the director of education at the partner Park organization, where I had worked closely with Taavi to launch the program. In addition to collecting data, I led several educational activities, such as a photography walk, and regularly assisted youth with field identification and other questions that emerged.

There were also nine environmental professionals that served as guest educators during the course of the program. They were invited to speak about their area of expertise and their own learning pathways, as well as to lead data collection or environmental interpretation activities. These activities ran from 1 hour to several hours in length. Guest educators (and activities) included ornithologists (bird banding); an inventory ecologist (moth identification); a restoration ecologist (watershed restoration); a conservation planner (data visualization); horticulturalists (landscape restoration and management); an urban naturalist (edible plants); and a herpetologist (salamander survey).

There were 11 high-school-aged youth participants who came from socioeconomically and ethnically diverse backgrounds and abilities. Youth ranged in age from 14-17 and were rising 9th, 10th, and 11th graders. They attended two public magnet schools (n=5), two public neighborhood schools (n=2), one public charter school (n=1), and a private regional school for deaf and hard of hearing youth (n=3). To assist in communications between deaf, hard of hearing, and hearing participants, there were two American Sign Language interpreters present during program activities. When asked to describe their racial and/or ethnic backgrounds, youth described themselves as Black (n=2), Chinese American (n=1), Filipino (n=1), Mixed race (n=2), Puerto Rican (n=1), White (n=3), and White/Jewish (n=1). Five of the youth self-identified as male and six as female.

The diversity of youth participants was not coincidental. The Park organization had a deliberate strategy for extending the reach of environmental education experiences beyond typical White and/or affluent audiences. As an organization, they focused on recruitment and pedagogical strategies that would make this as successful as possible. Youth were recruited into the program by Taavi, the lead educator, via one of several approaches. Some had participated in the organization's high school program, which takes place during the school year (n=6); others had been junior counselors at the organization's summer camps (n=2); and others had been recommended by community-based partner organizations (n=3). The application process included a written application and an in-person interview where youth were accompanied by a parent or guardian.

4.2.4.4 Program culture

The Park organization had a philosophy and approach to education that held that nurturing a human community was an essential part of coming into community with nonhuman nature. In this spirit, Taavi and Selah, the two lead educators, emphasized authenticity and emotional connection with the youth in their teaching practice. This included frequent informal conversations with youth about difficult topics such as racism, sexual orientation, gender expression, family, and community circumstances. These conversations often took place during stewardship activities or down time and included the educators presenting an honest and open picture of their own personal identities and experiences. For example, both Taavi and Selah identified as mixed-race – Taavi as Japanese and White and Selah as Black and White – as well as queer. They talked openly about their own challenges, past and present, moving through community and educational spaces where they felt othered or isolated.

This was a behavior they described as “bringing your whole self” to the program and project, which was something that they encouraged me to do as a participant-observer as well. For me, this meant making my own positionality – as a White woman trained in European-based sciences, with children the same ages as the youth participants – transparent as well. I shared stories of having grown up in a large city and only coming to my own love and connection with nonhuman nature in my 20s. I participated in conversations that tackled difficult topics, primarily asking probing questions but also answering those questions that youth put to me about my own experiences and perspectives. I was also explicit about the nature of my project, the research questions I was asking, and the methodological approaches I was using. The lead to regular questions from the youth about my work, which I answered both informally and during several more structured group discussions.

Taavi and Selah had also made a commitment to approaching each youth with what they called “unconditional positive regard”. This was a phrase that frequently surfaced during our daily educator debriefing sessions as we discussed the youths’ progress in the program. When challenges emerged during these discussions – whether interpersonal or content oriented – Taavi in particular would steer the conversation back to a strengths-based lens on each youth, trying to identify how they could best support the youths’ growth and development. This combination of deep care for each youth and frank intimacy about their own experiences set a tone for the program, beginning during the retreat and extending throughout the summer, that created space for the youth to express themselves honestly not only with Taavi and Selah, but also with one another, myself, and the guest educators.

4.3 Methods

For this project, I have combined traditional qualitative methods and a nested case study approach (Yin, 2014) with naturalist approaches that allowed me to move beyond anthropocentric analysis of our data (Hultman & Taguchi, 2010; Pacini-Ketchabaw et al., 2016). Connecting social and natural science traditions, and including nonhuman nature as a central actor in learning, is fitting given that this project was conducted in partnership with an urban environmental education program which explicitly aims to dissolve boundaries between human and nonhuman nature. Both data collection and analysis were anchored in our research-practice partnership approach, which meant regular communications between the primary educators and myself before, during, and after the program and primary data collection phase.

4.3.1 Data sources

The data set includes fieldnotes and artifacts from program activities, along with audio recorded and transcribed interviews, youth group discussions, and educator debriefing sessions. I conducted 89 hours of participant observations over the course of the program. I captured observations using handwritten jottings that I later expanded into more detailed typed fieldnotes (Emerson, Fretz, & Shaw, 2011). Jottings also included small sketches of human and nonhuman natural elements. Fieldnotes were typically completed the day of the observation and always completed within the week observations were conducted.

My observational practice included notation of robust episodes of interest expressed through interactions between educators, youth, and nonhuman nature. These episodes lasted from 15 minutes to an hour or more, and were defined by youth expression of interest in the environment as evidenced by observable behaviors such as auditory cues (e.g., question asking, concentrated silence) or physical actions (e.g., leaning in, facial expressions). Episodes included human-human interactions (e.g., youth asking questions about environmental phenomena), human-tool interaction (e.g., use of field guides), and human-nonhuman interactions (e.g., tasting a wild edible plant).

At the end of each day, all youth and educators reflected on and shared their *highs/lows* for the day, which I captured as part of the daily jottings. They were also asked to reflect on their highs/lows for the entire summer on the last day of the program during an audio recorded and transcribed final discussion. To supplement these observations and discussions, I collected artifacts such as youth naturalist journals and photos taken by youth of natural features in the park. Additional artifacts included youth applications to the program, educational materials that educators used when leading activities, and email communications about program expectations from educators to guest instructors.

I conducted semi-structured interviews with both youth and educators. In an effort to center the materiality of the park as a site for learning, I chose to conduct these interviews outdoors. This idea was inspired by other works that have explored the significance of walking for embodied learning in informal learning settings (Marin & Bang, 2018; Skov, Lykke, & Jantzen, 2018). I asked each interviewee to guide me on a walk or to select a place to sit in a part of the park of their choosing.

I conducted 1-hour interviews with educators and organizational staff before the program began that focused on organizational mission, program infrastructure, and educator practices. I also explored each educator's connection with the nonhuman natural world. During the program, I also held daily debriefing sessions with the two primary educators during which I took notes. In addition, I held four weekly recorded debriefing sessions. These ranged from 45 minutes to 1 hour 40 minutes in duration.

I conducted 20 to 30-minute interviews with each of the youth at the mid-point of the program that focused on their interest coming into the program and how they perceived their interest to be developing through program activities. An interpreter was present for interviews with the three youth that were deaf or hard of hearing. Two of the youth that were hard of hearing read lips and spoke; during the interviews they asked the interpreters to clarify a few questions and responded entirely using their own voices. For the youth that was deaf and did not typically vocalize two interpreters were present, one interpreted each question and another voiced the youth's response to questions. I also led three large group discussions with the youth, which ranged from 30 minutes to 1 hour 20 minutes and were recorded. All of the audio recorded interviews, group discussions, and debriefing sessions were transcribed for analysis.

4.3.2 Data analysis

In keeping with my research-practice approach, data analysis included regular and on-going work with practitioner partners. This included early reflections on interest development by both university and practitioner researchers during the program itself, which were captured through notes and recorded educator debriefs. These daily and weekly debrief sessions served as a form of ongoing analysis of observational data. For example, we discussed apparent resistance to structured activities and arrived at consensus on whether specific instances be considered counter evidence of interest (e.g., using cell phone for unrelated social media) or independent forms of interest expression (e.g., youth disengaged from group discussion, but using cell phone to look up bird identification).

After the program was complete, I took the lead in examining fieldnotes in order to identify robust episodes of youth interest expression and develop preliminary themes to describe these episodes. I then reviewed the themes and example episodes with the practitioner researchers and devised more specific codes through our conversations as a team. From these conversations, I operationalized the use of the codes by creating a template for structured case summaries that incorporated agreed upon codes and sub-codes (see Appendix B). The case summary structure included: youth interest expression through 1) interactions with other humans (e.g., other youth, educators), 2) interactions with nonhuman nature (e.g., flora, fauna, landforms), and 3) use of naturalist practices (e.g., journaling, using field guides).

I then created four structured micro-ethnographic case summaries (Miles et al., 2014) that focused on the relational processes that supported youth environmental interest development. The cases were selected by the research team to reflect a range of youth interest expression and programmatic infrastructure. Each reflected a unique relationship between a specific youth and an element of nonhuman nature. Structured case summaries ranged from 15-20 pages and included vignettes of robust episodes of interest. I began the summaries with an analysis of the fieldnotes and then triangulated and synthesized data from the interviews, youth group discussions, educator debriefs, and artifacts.

I then reduced the data set to more concise case summaries of 2-3 pages each to make these more digestible for the practitioner researchers on the team. I developed a cross case analysis guide for each team member to use when reviewing the case summaries. The analysis guide included descriptions of agreed upon codes and thought questions which each individual used to consider the data set (see Appendix C). We then met as a team to discuss the four cases and co-create meaning of the data set together. This discussion included revision of some codes and cases and further reflection on relevant educator practices and program infrastructure. In this way, we moved from a deductive to an inductive approach, beginning with theory about interest development and then moving closer to the data as we developed more specific findings.

4.4 Findings

In this section, I present four focal cases on youth and nonhuman nature nested within the larger program case study. I begin with micro-ethnographic sketches (Spradley, 1980) of the connections between each of four youth and an element of nonhuman nature that aim to show how youth environmental interest expanded throughout their participation in the program. I then present a cross case analysis of these cases in order to point to three program infrastructures that contributed to a deepening youth environmental interest development. I use evidence from participant observations, youth and educator interviews, youth and educator group reflections, and artifact analysis to identify these three program infrastructures. Each of the infrastructure elements builds on the role of relational processes between and among youth, educators, and local elements of the nonhuman natural world. These programmatic infrastructures included: 1) encouraging physical interaction between humans and nonhuman nature to transform fear/apathy into affinity; 2) offering meaningful opportunities for youth to be caretakers of land and waters; and 3) exposing youth to possible visions of their future selves.

4.4.1 Focal cases

As a research team, we selected these four cases to reflect exemplars of youth transition from basic interest in science and the environment to a deeper environmental interest over the course of the summer. As with all program participants, each of these four youth came to the program with an articulated interest in the environment which then observably deepened over the course of the summer. We also selected the cases to reflect the diversity within the youth participants in terms of educational experiences and both gender and racial identification (see Table 5).

The cases include two youths – Charlotte and Jeremiah – who arrived with prior experience and knowledge about nonhuman nature and two youths – Daisy and Rashawn – who had less experience with the nonhuman natural world than other program participants, but had both expressed strong interest in science as a school subject and who looked forward to spending time outdoors during the summer. Although each youth was primarily associated with one of the program infrastructures, analysis revealed how other program infrastructures were also important for the youth.

Table 5. Summary of four microethnographic cases

Case name	Description of nonhuman nature	Description of primary youth	Primary program infrastructure driving youth interest
Charlotte & the Wildcat Hollow Watershed	300-acre watershed that included urban residential neighborhoods & portions of a city park	Charlotte, a 16-year-old White girl, attended a public magnet school	Caretaking of land and waters
Jeremiah & the blue jay	Common songbird found throughout urban and suburban areas; easily distinguished by its blue crest	Jeremiah, a 15-year-old Mixed race boy, attended a public magnet school	Developing possible visions of future self
Daisy & the juniper geometer moth	Leaf-like looking moth; found throughout Eastern North American	Daisy, a 15-year-old White girl, attended a private school for deaf & hard of hearing youth	Physical interactions to transform apathy into affinity

Rashawn & the arachnids	Invertebrates characterized by eight legs; spiders are the largest group; also includes harvestmen	Rashawn, a 15-year-old Black boy, attended a public neighborhood school	Physical interactions to transform fear into affinity

4.4.1.1 Charlotte & Wildcat Hollow Watershed

Charlotte began the program with a goal of trying to figure out next steps for her future. From the very first days at the retreat, she approached adults with specific questions about their own experiences and wondered aloud about her own pathway. Her focus over the summer was most frequently tied to our work in the Wildcat Hollow Watershed, a place where her growing interest and commitment to stewardship developed.

An important aspect of Charlotte's background was that she began the program with greater familiarity with the Park and Park programs than many of the other youth participants. She was described by Taavi as being from a "Park family", by which he meant that she participated in summer camps as a younger child, had been a junior counselor as she got older, and had attended Park programs with her family. This familiarity was reflected in Charlotte's consistent use of the common names of plants and birds during Park walks when many of the other youth were just beginning to learn these things.

This strong foundation may have contributed to Charlotte being one of the youths that was most engaged in using the field journal. From the very first time it was introduced, Charlotte began ardently keeping notes. She kept species list of all kinds – birds, wild edibles, moths – and at one point even asked me to record a list of macroinvertebrate species so that she could focus on identification. In addition to the species lists, her journal included detailed and labeled drawings of tree identification characteristics and a list titled "interesting things" which included: bird banding; the educational research project we were engaged in; chronic wasting disease/deer problems and solutions; making sense of data; and wild edibles and medicinal plants. Charlotte described liking math and science in school and demonstrated strong skills in both of these areas. She also had an interest in drawing and art, and shared a detailed colored pencil illustration of a butterfly with the group.

4.4.1.2 Jeremiah & the blue jay (*Cyanocitta cristata*)

Jeremiah wanted to live as a bird. A blue jay (*C. cristata*) he said, or perhaps an American robin (*Turdus migratorius*). When he talked about his interests during his interview midway through the summer he said:

> *I want to learn more about animals, especially birds. I say birds fascinate me, and I kind of want to live as a bird…Because I'm sure it's stressful at times but it seems nice being able to fly away and just getting away from the big city at times and live in a nice forest like this. I'd want to do that.*

Before beginning the program, Jeremiah had some prior experiences watching birds in a neighborhood park near his home. This led Jeremiah to being one of the youths who entered the program able to name a few birds on sight. His neighborhood park had a recreation facility where a community-based organization ran programs, primarily for seniors and teens. Jeremiah had been attending programs there for a few years, and eventually became one of the youths for whom they paid a monthly stipend to help as needed. It had been adults at this organization, which was a partner with the Park organization on several projects, that had let Jeremiah know about the paid summer internship program in the Park.

For Jeremiah, who did not express much interest in school subjects and had not participated in any previous programs with the Park organization, his interest in nature did not have the academic tenor that Charlotte's did. For example, his field journal was nearly empty. Still, he was one of the keenest observers in the group and he became quite skilled with identification, not just of birds, but of other flora and fauna as well. His tendency was to slow down on Park walks, looking and listening closely as other youth continued to walk and talk ahead of him.

Taavi remarked that Jeremiah's connection with the nonhuman natural world was "beyond the utility of the thing." Instead, Jeremiah had an affinity for nonhuman nature that was expressed in quiet and artistic ways. He could often be found taking photos of creatures and landscapes, which he would manipulate later with filters to create artistic renditions of what he had photographed. He was also a leader, sharing his newly developing knowledge with his peers. For example, he quickly learned how to use Merlin, the bird identification app, and immediately explained to other youth how to use it in a clear and patient manner. His transformation over the course of the summer was going from a cautiously interested, but somewhat reserved participant, to someone who began to articulate an image of himself engaged in the natural world in a professional way.

4.4.1.3 Daisy & the juniper geometer moth (*Patalene olyzonaria*)

Daisy had come to the program with a strong interest in science. She described herself as a very good student who had skipped fifth grade when she entered the school that she currently attended. On several occasions she would bring up activities that she had done in science classes in school and relate them to a program activity. This wasn't presented in a competitive way, but rather with an apparent sense of excitement about being able to make connections between things she already understood and some of the new ideas we were exploring. She was one of the most verbally participatory youth, often asking and answering questions during many of the program activities.

Daisy had applied to and been accepted at a Space Camp for that summer, but became convinced to participate in the Park program when she learned that it would include active engagement with a community of people that were also interested in the environment. She explained in her interview why she decided to pursue this program:

> *I was taking biology that year and I just wanted to learn more than what was just in a textbook because I don't like learning from textbooks. I like learning by doing things. I like learning from stories and other people's experience. So that's why I just felt like, 'Oh, I want to join this.'*

On just the second day of the program retreat, Daisy connected her analytic approach to understanding natural phenomena with a newly discovered interest in moths. This brand-new interest served as an example of how she liked to learn by doing things and from other people's stories. Her inquiry into moth life histories and identification, and her connections between moths and other ecological concepts, first emerged during discussions with and observations of an ecologist conducting moth inventory and identification. Over the course of the summer, this strong interest in moths and their role in ecosystems continued to flourish through her own independent inquiry.

4.4.1.4 Rashawn & the arachnids

Rashawn approached many of the program activities with authentic curiosity and an inquiry stance. He consistently asked clarifying questions, checking in on new vocabulary, asking for explanations on approaches, and vocally expressing a desire to expand his understanding of the many topics we cover. Rashawn's desire to learn and experience new things was reflected in his explanation for why he wanted to participate in the summer program:

> *Because I never actually took the time to go outside and go in the woods and actually see insects. And I like seeing new things. And when I see new things, it makes me a little excited because I never seen it before. And I like to learn about new things I've never seen before and types of species.*

He cited science as his favorite school subject and spoke fondly of the science teacher who told him about this program, got him the application, and helped make sure that he had all he needed to complete it. He said that science was his favorite class because it involved “looking at new things and knowing new things I've never seen before.”

Rashawn especially valued the community that developed over the course of the summer and frequently brought this up during our daily highs/lows. He also spoke informally with educators about how much he appreciated “just being with everyone” as a primary benefit of being in the program. His desire to be part of a community of naturalists was also reflected in his regular request to be photographed doing program activities.

Rashawn demonstrated a major transition in his orientation to nonhuman nature over the course of the summer. He began the summer with a vocal fear of arachnids, especially spiders, and ended up as the youth most likely to point them out, name them, and even touch them when appropriate. His story is an important one, because fear of nature, especially creepy-crawly creatures, was a common challenge that the Park organization worked to address.

4.4.2 Cross case analysis: Infrastructures for deepening interest

In this section I examine infrastructural elements of the Youth Naturalist program that supported the enrichment of environmental interest for the youth program participants. I focus on these four cases because of the ways that the cases exemplify larger patterns within the data set. In keeping with my goal to use relational processes as a unit of analysis, I emphasize that these infrastructures are not distinct from one another. Instead, they are entangled in ways that support a deepening development of youth interest. However, I present each infrastructural element separately in order to explore them in greater detail.

4.4.2.1 Encouraging physical touch to transform fear/apathy into affinity

Direct, physical contact with elements of nonhuman nature supported the deepening of environmental interest for youth. These physical interactions often emerged during structured program activities where educators modeled passion and affinity for nature. Both Taavi and Selah frequently displayed their own curiosity about and love for nonhuman creatures during program activities, including park walks and stewardship sessions. Selah in particular, was very enthusiastic about less charismatic creatures such as moths and spiders, encouraging youth to observe them closely and touch them gently. For example, when a guest educator named Chuck joined us for a two-day session to explore moths during the retreat at the start of the summer, Selah displayed an infectious excitement for the moths. Selah's willingness to touch the moths served as a catalyst for Daisy's developing interest in moths, which Daisy had not considered before this program and which became a focal interest for her over the course of the summer.

Chuck was an inventory ecologist with a regional conservation organization where his job was to conduct inventories of flora and fauna in protected and potentially protected landscapes. He had excellent overall natural history field skills and specialized in moths, which were the focus of his time with us. As the youth were roasting hot dogs over a campfire one night, Chuck set up a simple moth trap which consisted of hanging a sheet between two trees and placing a UV light behind it. At about 10pm he turned on the light and all the youth and educators gathered near the sheet to see what moths and other creatures might be attracted to the light. Chuck provided some background information about moths as the creatures began gathering.

Selah became vocally excited almost as soon as the UV light went on. She had developed a strong interest in moths the previous summer when Chuck had done a similar activity. Now, she sat down close to the hanging sheet, letting moths land on her and gently reaching out to scoop individuals into her hand in order to look at them more closely. Most of the youths were shrieking loudly at this point; they were excited and nervous about being close to so many flying insects. Dozens and dozens of moths brushed near us as they flocked to the sheet, including some of the more charismatic moths such as the 8-spotted forester (*Alypia octomaculata*), Isabella tiger (*Pyrrharctia isabella*), and pale beauty (*Campaea perlata*). Selah continued to enthusiastically model her own interest as she asked who else would like to touch a moth. A couple of the youth, including Daisy, moved in closer. Later in her interview, Daisy reflected back on this moment this way:

> *I literally asked Chuck, 'Aren't moths just brown?' He's like, 'No. No, they're not.' [laughter] And I was like, 'Okay.' And I'm like, 'Why are moths attracted to this light?' And he was like, 'I'll tell you the story later.' And then Selah said, 'It'll make you cry.' And Selah was being dramatic as always but that intrigued me [laughter]. So, I saw all the little moths and I decided, 'Oh, I just want sit right there,' really close.*

Daisy's reflections reveal her desire to physically engage with the moths, to sit "really close" to them. This was a new experience for her, which was mediated by Selah's modeling of engagement, by Daisy's desire to learn more about something that she hadn't looked at closely before, and by the moths themselves which had joined our group.

Selah's enthusiastic willingness to engage physically with nonhuman creatures had a similar impact on Rashawn, but with arachnids. Rashawn began the program afraid of spiders. When asked to share what he remembered about the retreat, he cited being afraid of "the big spider in the cabin". One night the spider had presented itself right next to where Rashawn was sitting in the boys' cabin. He described the scene several times over the remainder of the summer, talking about how huge and scary the spider was, and how one of the other youths shooed it out of the cabin, which was not something he thought he could do.

During the first week of program activities in the Park, we all took a hike down a trail that followed one of the small Park streams. Everyone, including youth and educators, was asked to take photos of anything that caught their eyes in one of three categories: things they were curious about; things that give them the chills; and things they would like to change. Rashawn's photo of something that gave him the chills was of a large black and white wolf spider (*Lycosidae sp.*) that appeared to be nesting between a downed log and a stand of stinging nettle (*Urtica dioica*). While he described how the spider gave him the "heebie-jeebies", he also correctly identified that this spider was in the wolf spider family, suggesting that he was both afraid of and curious about the creature, repelled by it while also recognizing it and calling it by name.

Towards the end of the photography hike, several youths began to cluster together on the trail. Selah had a daddy long legs (*Opiliones sp.*) in her hands and began to encourage Rashawn to let it crawl on him. (Note that this type of daddy long legs is sometimes called a harvestman and, while it is an arachnid, is not a true spider.) Daisy and another youth immediately gathered around them, letting the daddy long legs crawl on them and saying that it didn't feel like anything at all. The other youths who had been farther down the trail joined the group while Rashawn and Selah remain at the center of the knot. Voices became elevated as more and more people began encouraging Rashawn to let the daddy long legs crawl on him with a teasing but kind tone. In false starts, Rashawn put his hand close to the daddy long legs and then pulled it back. Rashawn said “Nah – I can’t do this” at the same time that he smiled an exhilarated, broad smile and continued to put his hand forward – once, twice, three times, more. At one point he broke away from the knot of people, walked around it, and then came back to his original position at the center.

At last Rashawn put out his hand and let the daddy long legs crawl on him. His smile became even bigger and reflected a radiant joy. The entire group was ecstatic and erupted into loud cheers. Selah said, “I am so proud of you, I am so proud of you”. Spurred on with confidence, Rashawn then told the group about the large wolf spider that he had photographed earlier. He took the lead as we hiked back, guiding us onto a small, single track trail and excitedly narrating our way, saying that it wasn’t much farther. As we came around a large bend in the trail, Rashawn guided us to the stand of stinging nettle with an enormous wolf spider sitting on one of the leaves.

In Rashawn’s case, Selah’s willingness to look closely at and touch the spider was further enriched by Rashawn’s fellow youth participants, who encouraged Rashawn’s growing interest in arachnids. The group’s encouragement during Rashawn’s breakthrough episode with the spider was an example of the ways that the human community that had been fostered by Taavi and Selah supported youths’ willingness to engage with nonhuman nature in new ways, overcoming earlier fears and exploring new interests. The group cohesion, which was regularly referenced by other youths as well, supported Rashawn in his progression from terrified to tentative to comfortable with arachnids over the course of the program.

For both Daisy and Rashawn, these initial robust episodes led to an ever-deepening interest in the creatures over the course of the summer. For example, Rashawn became our resident spider-man, regularly pointing out large wolf-spiders and daddy-long legs. These two types of arachnids became touchstones that he would look for and engage with on walks and during activities. During one stewardship activity about halfway through the summer, a couple of youth discovered an enormous wolf spider with an egg sack hanging off of its belly that was the size of its whole abdomen. Rashawn rushed over to look more closely at the spider and this time he showed absolutely no fear. By the end of the summer, Rashawn's fear of the creatures seemed to have disappeared altogether. Selah noted during an educator debrief late in the summer that Rashawn had even begun picking up spiders on his own.

Daisy also transformed her orientation towards moths over the course of the summer. This began with the moment that Selah inspired Daisy to sit "real close" to the moths. Beginning the morning after Daisy was first introduced to moths, she began a series of inquiries to learn more about moths and their roles in ecosystems. That morning, Daisy began firing away questions at Chuck who had returned for another moth activity. This lasted for over 10 minutes while Chuck effortlessly toggled between this exchange and revealing and naming the many moths that had fallen into a trap he had set the night before. At one point, a small, russet colored moth, a Juniper geometer (*Patalene olyzonaria*), landed in Daisy's hair and the two of them – the girl and the moth – sat in stillness together. The following week when the youth were asked to say what they liked best during the retreat, Daisy said that her favorite thing was learning about the moths and having them land on her.

Over the course of the summer, Daisy began independently seeking out additional information about moths using field guides from the small library we created in the room where we met each morning in the Park. On several occasions during quiet moments, Daisy would look through the field guides, marking pages of moths we had seen and making notes in her field journal. By the end of the summer, she had written four pages of notes about moths in her journal about how to find and identify them. Her journal also included a list of species she'd like to "learn more about NOW" (capitalizations hers).

During a debrief session with the educators, Taavi reflected on the ways that they had intentionally structured activities to strengthen youth connections with nonhuman nature.

> *And I think, thinking about what we chose to research…we know you're going to have these up-close experiences with living things. They're like relatively dynamic. It's like different than if we're doing a plant survey, right? Like some kids geek out about plant surveys but it's not everybody's bag and you're likely to catch more people when things are like bouncing around and have like cool feeding stories and cool moving stories and those kinds of things.*

These cases exemplify the way that physical touch had a positive impact on youth interest, especially regarding creatures such as moths and spiders that are often viewed at best as non-charismatic and at worst as frightening. Selah's modeled enthusiasm involved more than just talking about the creatures and making close observations. It involved direct physical contact, which both Daisy and Rashawn took up in their own behaviors, eventually overcoming their own discomfort and developing a new interest. This physical contact between human and nonhuman nature was a deliberate part of the program infrastructure.

4.4.2.2 Providing opportunities to be caretakers of land and waters

Enthusiastic educator modeling and physical engagement with the nonhuman natural world also happened during stewardship. Taavi typically set up the stewardship activities for the group and would throw himself into the work on even the hottest and most uncomfortable days. He never shied from taking on the most challenging of the stewardship tasks, which set a standard of engagement for many of the youth.

The program was structured to tie stewardship with scientific inquiry through discussion of larger environmental issues, particularly urban watershed health. Each week during the program, we visited a small stream in a nearby park which was part of the urban Wildcat Hollow Watershed where the Park organization had been doing ongoing ecological restoration. During the visits, youth surveyed the stream for aquatic macroinvertebrates and salamanders, both of which can be used as indicators of water quality and stream health. Aquatic macroinvertebrates are small insects, often in the larval stage of a flying insect such as a dragonfly, which can be seen with the naked eye but can still be tricky to identify given the subtle features that are needed for positive identification.

Similar to Selah with the moths and spiders, Taavi modeled tremendous enthusiasm during these activities, often heading to the water first, flipping rocks to look for creatures, and loudly encouraging youth to explore the water with him. Rather than identifying the creatures for the youth, Taavi would ask questions that drove the youth to look more closely at key identifying characteristics and would then point them towards the pictorial identification tools that we had laminated and brought into the field. Charlotte embraced the surveying process, meticulously working to identify specimens even after other youth had stopped for lunch. She documented the number and types of species in her field journal and was one of the only youths to voluntarily engage in this practice.

During the second week of the program, we were visited by Kate, a guest expert who was a restoration ecologist for the Park organization. As Kate described the long-term project to restore Wildcat Hollow Watershed, the group listened from their perches on downed logs that were adjacent to one of the small streams where we had looked for macroinvertebrates that morning. She told them that “All the bug info you collect is getting sent to the scientists that are working on this project”, which reinforced the educators’ goals of making the scientific inquiry relevant and meaningful. She also passed around a booklet that described how urban watersheds function and what regional strategies could be used to improve watershed health, especially ones that employed open spaces such as parks. Several of the youth showed genuine interest in exploring the booklet, taking their time leafing through as it made its way around. As the passing of the booklet slowed to a halt, Charlotte called out for someone to pass it to her so that she could also take a look. She spent several minutes quietly looking through the booklet as Kate continued her presentation.

When Kate asked the group if anyone was interested in architecture, engineering, or design work, Charlotte piped in with a loud “Yes”. Charlotte then began to dominate the discussion, asking Kate a series of questions about the watershed project beginning with some general questions, such as “When are you going to start the project?” and “When will the information be released to the public?”. She then shifted towards design-oriented questions, such as “How do you build a stream that resembles a natural stream?” and “How would you interject life in the stream?” Charlotte displayed a similarly intense engagement with a different guest educator the following week. Emma, a planning coordinator with a regional conservation nonprofit, came in to lead a series of activities on data visualization about urban watersheds. Charlotte was again one of the most engaged participants, asking and answering questions in the large group and then quickly jumping into the mathematic calculations Emma asked them to do. Charlotte cited these activities with Kate and Emma as her high at the end of each of these days.

Charlotte’s intellectual engagement with watershed issues was matched by her focused work during the stewardship activities. She embraced stewardship and frequently cited it as her favorite activity, both during our daily highs/lows and also when introducing herself to guests. Even one of the most strenuous stewardship activities – moving large boulders to repair a rain garden – was a favorite of Charlotte's. This rigorous stewardship work is an example of Charlotte's physical engagement with nonhuman nature. Charlotte's connection with Wildcat Hollow Watershed exemplifies how the program linked science and stewardship experiences in ways that helped youth meaningfully connect their developing scientific understanding of the world with their ability to see themselves as caretakers of land and waters that could support Park and watershed health.

4.4.2.3 Exposing youth to visions of their possible future selves

The program was structured to help youth make explicit connections between activities and their developing visions of their future selves in order to help youth transition from burgeoning interest to an abiding and richer interest. This was largely done through regular exposure to a variety of environmental professionals. It allowed youth to make connections between experiences with program activities, interactions with environmental professionals, and visions that they were developing for their possible future selves.

Taavi primed guest educators to think about their own pathways and be prepared to share them. He sent all guest educators an email in advance of their visits asking them to consider how they had come to their current jobs. With this priming, many of the guest educators shared information about their educational and professional pathways as they introduced themselves. Taavi invariably asked for additional information from all of them, encouraging them to provide detail to their stories and inviting youth to ask additional questions. This created an infrastructure for a relational process between youth and environmental professionals wherein youth began to seek additional information from these guests both during group discussions and more informally in one-on-one conversations.

This also created a climate for youth to openly think about their own future pathways. For Jeremiah, this began during a robust episode on the second day of the program retreat. At 7am that morning, our group had crowded into in a very small room at the biological research station where we were staying for the week. We had risen early that morning to observe scientists perform their regularly scheduled bird banding, which is a process that is used to better understand the health of bird populations. By recording the location and other data for each bird and then sharing data with similar research stations around the world, scientists can better understand things such as bird populations, migration, and habitat use.

Some of the youth were just beginning to be acquainted with birds, and one even expressed a marginal fear of them. For Jeremiah, who had come to the program with an existing interest in birds, the bird banding helped give definition to his developing interest and skills, which continued to grew over the course of the summer. That morning, we watched the lead scientist, Abby, gently examine each bird in her hands as she identified, weighed and measured them. The youth and educators were nearly silent as they watched closely, sometimes smiling, and sometimes nodding and leaning in to see more closely.

Abby was very adept at firmly and gently holding each bird, head pressed between her pointer and middle fingers while the body of the bird was cupped inside of her hand to keep it still. She easily identified every one of the dozens of birds we saw that morning – first a teeny tufted titmouse (*Baeolophus bicolor*); then a female American redstart (*Setophaga ruticilla*); next an eastern phoebe (*Sayornis phoebe*); then another redstart, this time a male close to molting its flashy red and black feathers; then an even teenier blue-gray gnatcatcher (*Polioptila caerulea*), whose tail was as long as its body; and on and on, bird after bird, identified and measured without hesitation. The whole process, which combined intellectual rigor and gentleness, took no more than a minute per bird.

Jeremiah, who was sitting on a bench behind a couple of other youth that were closer to the desk, immediately asked Abby how she scored the fat, which was one of the measurements she took. Jeremiah was smiling and leaning in as she demonstrated again how to blow on the belly feathers to reveal small, yellowish fat deposits just beneath the skin of the white belly of the diminutive tufted titmouse (*B. bicolor*). The room was remarkably quiet during this demonstration, and several youth leaned in and nodded along with Jeremiah. However, Jeremiah was the most engaged with the scientist, who he continued to pepper with questions, such as "How would you catch an eagle?" His questions about the process continued as we headed out to the field to look at the mist nets used for trapping the birds.

Later that evening, as we hung around the cabin, Jeremiah remarked that what he liked the most that day was the bird banding and, "the fact that she (Abby) seemed so relaxed and calm. Animals excite me. Especially birds." Later during an educator debrief about the retreat week, Taavi recalled Jeremiah's comments from that night.

> *He was recounting the story that the woman at the bird banding place told us about how she got into it. And he was like, 'Man, how do you even go about – that's what I want to do. Not be at a desk and be out doing that.' He was like, 'This is something I could be really interested in, but how do you do it?' So, I thought that was just another thing where that to me was truly showing – Okay, he saw somebody for a position and he was like, 'I could do*

that. That would make me really happy.' And he was trying to connect the dots with, 'What are the steps to get there?'

The experience bird banding and hearing directly from Abby about her pathway helped Jeremiah connect a prior interest with a possible future career path. The following week, Jeremiah brought up the bird banding when he is asked to share his favorite retreat activity. Then, in his interview, Jeremiah commented,

The bird banding, whenever that happened, I enjoyed experiencing it and watching them do that. I would love to do that.

The exposure to environmental professionals who were able to articulate their own pathways and effectively express their own ongoing interest was critical for many of the youth. It opened up youths' understanding of how becoming expert could actually reveal more questions and opportunities to learn about a subject. This is an essential aspect of scientific inquiry and was one that youth recognized and vocalized. For example, Daisy cited the benefit of seeing how much an expert, such as Chuck, still had to learn about the subject of moths. This allowed her to see environmental knowledge not as a thing to be possessed, but as a process that could be engaged in throughout her life.

Charlotte also articulated how the program activities were helping her think about her future self. Over the course of the summer the watershed work helped her frame a possible career path. During her interview, she described her fascination with how the Park organization was taking a large regional problem and trying to address it in a specific area – the Wildcat Hollow Watershed. She was especially interested in the problem-solving aspects of this, which married her interest in both engineering and outdoor work. On the last day of the program when the youth were asked to reflect on highs and lows from the entire summer, Charlotte brought up her new understanding of possible environmental work as a career path, stating:

> *I think that something that I'll take away from this... I think just like knowing that working with the environment is a career option to explore cause before I was just like oh, science, something with science, and then I'm thinking I like definitely wanna do something with the environment, yeah, be out in nature.*

The engagement with environmental professionals supported what the educators called "science talk" and reflected a type of naturalist practice that the educators worked to encourage. Science talk included examples such as Jeremiah asking Abby about how to score the fat on the bird or Charlotte asking about the design elements of a stream restoration. This was a next step in building a stronger affinity for science and nature and for the development of a naturalist practice that complemented other practices, such as species identification. Taavi reflected during one of the post-program data analysis sessions on this kind of thinking this way:

> *But also like the thought process and like the depth of thinking and being presented with information, thinking about it and then having a question, is that a naturalist practice? You're like grappling with a system and trying to figure out what are the bounds of each of the little parts of it and how do they overlap and that's like a naturalist practice in my mind.*

4.5 Discussion

4.5.1 Using a learning ecosystem frame

Developing environmental interest and the adoption of an environmental identity is the result of complex and linked processes (Polman & Hope, 2014). Therefore, the use of an ecosystem framework, which embraces complexity rather than reduces it, offers a useful tool for examining how interest transitions from initial interest to individual interest. This paper uses an ecosystem framework to explore the impact of one informal science program on youth as they transition from having nascent environmental interest to an individual interest that supports a burgeoning environmental identity.

Although learning ecosystems are often conceived of as large networks, the scale and boundaries of an ecosystem are not absolute. Nor are they arbitrary. Instead, ecosystem boundaries are defined by humans in an effort to conceptualize and make sense of patterns and processes within the unit we are attempting to examine (Horton, 2018). In this case, I have delineated the boundaries of the learning ecosystem of study around one informal environmental education program and its activities and participants, including the land, waters, and nonhuman creatures that were essential elements of learning. I also recognize the program as a constituent of the larger regional learning ecosystem that is sits within, much in the way that the small Wildcat Hollow Watershed is nested within a series of larger river watersheds ultimately culminating in the Mississippi River Watershed. The nested nature of the learning ecosystems in this region – from program scale to citywide learning ecosystem scale – is relevant for considering how program infrastructures might support evolving youth interest and identity development and the migration to other learning opportunities.

My use of an ecosystem framework supports notions of how connectedness – of learners, educators, and place – shapes learning through relational processes (Kawagley, 2006; Nasir & Cooks, 2009). In this program, these relational processes included robust episodes between humans, including program educators, guest educators, and youth-youth relations. They also included robust episodes between human and nonhuman relations, primarily through physical touch that was driven variously by youths' curiosity, caution, and care. The relational processes also involved other physical elements of the world, including naturalist tools such as field journals, field guides, and apps. By looking deliberately at the interactions among and between these actors, I have worked to reveal the complexity involved as youth begin to see themselves as naturalists, actively engaged in the process of relating to and caring for land and water, now and into the future.

Through four micro-ethnographic sketches of youth nested within a program case study, I worked to center relational processes by identifying three types of infrastructure supporting the youths' transition to becoming environmental people. These elements were: 1) exploring connections between youth and nonhuman nature; 2) positioning youth as agents in the care of land and waters; and 3) offering opportunities for youth to envision their future selves as environmental people. Although I have presented these as separate elements in order to explore them in detail, the examples also illustrate how deeply entwined these elements are. For example, Charlotte's physical contact with nonhuman nature was primarily through stewardship activities. This watershed stewardship was a direct outgrowth of her relations with both program and guest educators, which contributed to her developing vision of herself as a caretaker of land and waters, perhaps as an environmental engineer or designer. This entanglement of infrastructural mechanisms is indicative of the complexity within a learning ecosystem which cannot be separated into its constituent parts, but must instead be recognized as a space where all actors, including nonhuman actors, have agency and are influencing one another (Barad, 2007; Hecht & Crowley, 2020).

4.5.2 Designing for transformation

Given the complexity of environmental interest and identity development, how does using a learning ecosystem framework influence the ways that we might design informal science programs? Does considering relational processes between and among humans, nonhumans, and naturalist tools change how we might approach developing activities? Because this project was conducted as part of a collaborative research-practice partnership, this was a question that was salient not just for myself as a university researcher but also for the practitioner researchers throughout the project. For example, Taavi reflected on the ways in which the educators considered the landscape itself and the stories the landscape holds as an element of the program design process. His thinking reveals the ways that the educators worked to knit youth interest together with specific Park places and types of activities for maximum effect.

> *Like I think we make educational decisions, like practice, we make decisions for our practices based on if we think that a student is more interested in like the content…and the kind of story that I can tell you about the health of the water and the health of the park and the impact of our restoration work….Or like yeah, where are we sampling. Like being able to sample below a place where we do erosion control work. That for some students I think is like an intentional decision that we can make when we're telling the story about Kent, who's like really into restoration work, or Charlotte and Isaiah,*

who are into the green infrastructure aspect of our stewardship work. That's an important connection to draw for them.

This level of specificity reminds us that this program didn't just occur in *a park*, it took place in *this Park* and that we can't separate the human experience from the land itself (Tuck & McKenzie, 2015). As Taavi and Selah adjusted activities to meet youth needs throughout the summer, they considered how the stories of the Park itself connected with the stories of each of the youth.

The ongoing recalibration of the program over the course of the summer was something our team referred to as "adaptive management" during the educator debrief sessions. This was a reference to the ways that restoration ecologists approach landscape management as an ongoing and iterative process based on landscape response to prior interventions (Hecht & Crowley, 2020). This flexible and adaptive approach was fundamental to the program design because it was able to support the dynamic and idiosyncratic nature of interest development (Azevedo, 2015). Opportunities for self-directed and open ended inquiry can be valuable approaches to help move youth with existing environmental interest towards deeper interest development (Maltese & Harsh, 2015). The program's flexibility rested on loose structures and resources that allowed learners and educators to take advantage of unexpected and/or unplanned moments.

The informal library of field guides that supported Daisy's interest development in moths is an example of this. Neither the educators, nor me, knew what taxa might be of interest to the youth or if the field guides would be taken up at all. Nevertheless, we created a rich library with guides from the organization and our personal collections. Although we didn't use the field guides in formal ways during the program, we pointed out the library on several occasions, especially to highlight a book that might connect with something a youth had expressed interest in. The educators described this as a "low intensity" practice by which they meant that there was no planned activity using the library. The library was used regularly during down time by various youth including Daisy, who independently reached for the moth field guide on a number of occasions. This infrastructure allowed youth to meander through content at their own pace, eventually finding specific connections or "hooks" for their own developing interest (Azevedo, 2015, p. 281).

Experiences such as this were sprinkled throughout the summer and served to support youth as they transitioned into becoming environmental people, which often wove together the various program infrastructures. For example, in one of Charlotte's journal entries – a naturalist practice unto itself – she connected her intellectual curiosity about watersheds, her physical engagement with them through stewardship, and her potential future self as an environmental engineer. She kept a running list of "INTERESTING THINGS" (caps hers), which included the "watershed thing". She also created a two-page entry titled "RESEARCH – Watershed" that contained notes on how urban watersheds function and what engineering approaches could be used to improve watershed health. This kind of voluntary expression of interest that integrated the range of program activities was emblematic of how youth moved over the course of the summer from general interest in science and the environment to envisioning their future selves as environmental people.

These transformations did not occur in single, perceivable moments. Instead, the relational processes I observed between learners, educators, and nonhuman nature might be considered transformational threads being woven into the fabric of activities that support interest and identity over the course of an individual's life (Azevedo, 2018; diSessa, 2000). Pugh and colleagues theorize that transformative experiences like what I observed are related to interest, but move beyond basic motivational factors (Pugh, 2011; Pugh, Linnenbrink-Garcia, Phillips, & Perez, 2015). Instead, transformative experiences also expand the learner's perceptions of the world in ways that open space for the emotional and caring connections observed among and between learning, educators and nonhuman nature throughout this program.

Affective connection with scientific material – developing a "feeling for the discipline" – has been posited by Jaber and Hammer (2016) to be an inherent component of science inquiry and an essential factor for interest development. In this program, this feeling for the naturalist discipline relied on the relational processes between youth, educators, and nonhuman nature. While emotional expressions of interest may take different forms (Reeve, Lee, & Won, 2015), emotion was routinely expressed. For example, Rashawn expressed fear of arachnids, which transitioned to curiosity and confidence through his physical connections with the creatures. For Jeremiah, his affect – what he described as feelings of excitement about both birds themselves and the prospect of doing work with birds – was built on his witnessing the gentle and rigorous work of an ornithologist. For many of the youth, the affective aspect of their interest was drawn directly from the frequently modeled emotional engagement with nonhuman nature expressed by both Taavi and Selah.

4.5.3 Designing for community

The program design also contributed to a sense of community for the youth – with nonhuman nature, with one another, and with a larger community of naturalists and environmental people. Connecting with the natural world through human connections was foundational for the Park organization. This was taken up by the youth, as expressed by Daisy in one of her journal entries:

> *I think people who share a same/similar interest makes me more interested by allowing myself to learn more about my personal interest and gets me more excited because you can connect with people over an interest.*

We can see here how being an environmental person – a naturalist – was not achieved through individual interest alone and instead relied on becoming part of a larger group (Carlone, 2017). The deliberate design of a disciplinary community mattered for these youth in their transformation to becoming environmental people (Azevedo, 2013; Pressick-Kilborn, 2015).

Importantly, this community was extended to include nonhuman actors, which are also our relations (Haraway, 2016; Kawagley, 2006). Rashawn, during his interview, reflected on his connection with the land and nonhuman community through environmental stewardship.

> *Well, to me, what we do now is that we're helping the environment as in the plants growing instead of deers eating all the plants and all that. And we're making a – well, I wouldn't call it a forest, but we're helping the wildlife as in grow and last, so it can grow and be stronger than what it was…We're helping the whole environment, now that I think about it. We help the people who come here and spend their time here where it's not dirty. You don't see trash around. It's clean. And people who like to walk through the trails – so when people walk through the trails, they don't got to watch out for big sticks or nothing because we'll handle that. We'll get it out the way. And we'll make paths easier for the bikers. And we'll help stop the erosions. So that's when dirty water get into clean water, messing up the habitat for what we said like fish or tadpoles may live in. So, we could make their stream better and get new insects.*

This positioning of youth as caretakers of both land and water was integral to both the science and stewardship components of the program. It moved the physical engagement with nonhuman nature to an even deeper level where youth were not just interested in learning about nonhuman nature as other, but rather were connected with nonhuman nature as part of the same system or what Rashawn called the "whole environment". Rashawn included both humans and nonhumans in his description of the environment as he discussed the youths' efforts to improve the health of the Park for its many inhabitants. As was true for many of the youth participants, Rashawn saw himself as part of the environment and in active relation with the Park.

In this way, transformation occurred for not only the youth, but also the land and waters of the Park. It became healthier as a result of the youth interest and the youth deepened their interest as a result of the Park's increased health. This reciprocal relational process between human and nonhumans emerged through deliberate features of the program infrastructure. It is this type of transformed relationship between and among humans and nonhumans that is needed if we are going to transform our culture's connection with the earth in order to address critical environmental issues, such as climate change.

4.5.4 Implications and future directions

This paper explores how educators, youth, and nonhuman nature come together through relational processes to support environmental interest development in diverse learner populations. I have used a learning ecosystem framework to integrate methods from the social and natural sciences to better understand the development of environmental interest and identity development for adolescents participating in a paid summer internship in an urban park. While these findings are limited by the fact that this is a nested case study focused on just one program and four youth, the findings contribute to advances in both methodologies for and conceptualizations of interest and identity development in the context of learning ecosystems.

I aimed to interrogate how to approach methods for data collection and analysis when we accept that nonhuman elements also have agency in the systems in which we work (Barad, 2007; Kawagley, 2006). But as educational researchers, can we effectively balance our humanistic thinking with a post-humanist lens (Pacini-Ketchabaw et al., 2016)? In practice, it was difficult throughout this project for me to not center humans. My tendency to focus on human-human interactions, especially through language, was ubiquitous and challenging, as recorded in this fieldnote:

> *I'm trying today to do more looking and less writing. I find I am just recording dialogue, which is not what I want to do. (Fieldnotes, 7/2/19)*

Future work ought to continue to challenge approaches for data collection and analysis that shift the focus from the cognitive changes in individual youth to the interactions between elements of the learning ecosystem that include nonhuman nature. While my gaze remained primarily on humans, how might we continue to explore how to better reflect the agency of the moths and spiders in these processes, for example? This is true for learning ecosystems at multiple scales, from program-level to regional networks.

While the field may continue to benefit from measuring youth interest through program surveys or other tools, I am hopeful that my approach helps move the field beyond measurement of the presence of interest in order to explore the dynamics that support it and help it grow into environmental identity. The dynamic interplay between interest and identity remains a complex phenomenon to understand and describe (Azevedo, 2018). More descriptive work that looks at interest and identity development, particularly over longer time scales, is needed. For example, I would like to continue to engage with these youth participants over the coming years to better understand how their environmental interest and identities do or do not continue to unfold.

5.0 DISCUSSION AND CONCLUSIONS

Supporting the development of environmental people – naturalists for the 21st century – is an essential component for addressing the local and global environmental challenges we currently face (Tewksbury et al., 2014). My dissertation uses the conceptual frame of learning ecosystems to probe the complex nature of environmental interest and identity development. Specifically, I explore the potential benefits of using a learning ecosystem frame as both a theoretical and methodological lens by asking how this opens up ways of thinking about the complex phenomena of environmental interest and identity development which unfold in dynamic, non-linear ways across time and space.

My dissertation work includes two distinct threads. One is an exploration of the potential strengths of a more robust learning ecosystem framework, which I examine theoretically in Paper 1 and then empirically in Paper 3. The other thread is an investigation into how environmental interest develops within learning ecosystems, which I examine empirically in both Papers 2 and 3. Throughout these works, I aim to knit together concepts and methods from both the natural and social sciences in order to consider how their integration might inform the design and management of learning ecosystems that foster the development of 21st century naturalists.

5.1 Implications for methodological shifts

Finding ways to improve the design and management of learning ecosystems is a wicked problem – and the use of a more robust learning ecosystem framework can help improve the ways that we research and design in this space (Falk & Dierking, 2018). In Paper 1 of this dissertation, I argue that the learning ecosystem framework offers greater benefits for educational research when enriched with concepts drawn from the adaptive management of biological ecosystems. I interrogate the typical depictions of learning ecosystems, which place a learner at the center of the system and treat the ecosystem as a complicated set of interconnected elements rather than a true complex system (e.g., Bevan, 2016; National Research Council of the National Academies, 2015).

But learning ecosystems are complex, and recognizing this complexity means that we must accept that simple causal explanations for challenges in the educational system will not suffice (Jacobson et al., 2019). Applying ecological thinking provides conceptual tools that can help explore this complexity (Code, 2006). For example, how should we spatially bound a learning ecosystem? Should we use domains, such as STEM, to define the boundaries? Should we think of a learning ecosystem as having geographically defined boundaries, drawn around a city or community? I posit that a learning ecosystem, just like a biological ecosystem, is nested, multiscalar, and non-hierarchically structured (Simon, 1996). These nested learning ecosystems have porous boundaries which allow for ecosystem elements to migrate in complex ways (Horton, 2018). Because of the nested nature of ecosystems, learning ecosystem spatial boundaries can be drawn at both citywide (macro) and program (micro) scales.

I also propose moving away from placing youth at the center of the system and towards conceptualizing learning ecosystems as a host of interrelated elements that are in relation to one another. Ecological thinking supports this exploration of complexity by focusing on relational processes between actors as a unit of analysis for understanding ecosystem function. The use of relational processes as a unit of analysis supports a focus on interactions between and among system actors that include both human and nonhuman nature (Barad, 2007; Kawagley, 2006).

In Paper 3, I apply both of these conceptual shifts by 1) bounding the learning ecosystem at a micro-scale of a program and 2) putting into practice the use of relational process as a unit of analysis. In this paper, I focus on relational processes between and among human and nonhuman nature in order to understand how youth environmental interest and identity develop. In both the data collection and analysis phases, I worked to maintain my focus on relational processes by examining interactions between the different ecosystem actors. This included consideration of how human-human, human-nonhuman, and human-tool interactions were manifest during the program, and how they contributed to the youth interest development. A key challenge of this work was the authentic inclusion of nonhuman nature as actors with agency in the system. In practice I struggled to not focus on humans as the primary agents for learning and worked to use drawing and less-humanistic thinking to implement a multispecies approach (Pacini-Ketchabaw et al., 2016).

While my dissertation focuses on the study of environmental interest for youth, I believe the learning sciences more broadly would benefit from using relational processes as a unit of analysis. Setting and relational processes are key elements for learning (Nasir & Cooks, 2009; Pinkard et al., 2017). Therefore, attending to the material elements of learning ecosystems, regardless of settings or disciplines, could support researchers' efforts to explore the complexity of learning. I suggest that regardless of domain, the inclusion of nonhuman nature and place be considered central actors in the learning process (Bang & Marin, 2015; Tuck & McKenzie, 2015), precisely because we come into being in relation with the material world (Barad, 2007). Finally, a relational stance that recognizes that researchers are part of learning ecosystems fundamentally shifts how we understand the process of knowledge building (Patel, 2015). As a university-based researcher, I recognize that I both transform and am transformed by the learning places in which I work (Rosiek et al., 2019).

5.2 Implications for interest and identity development

Interest and identity development are complex endeavors that unfold through lifelong and lifewide opportunities (Azevedo, 2018; Penuel et al., 2014; Van Horne & Bell, 2017). The empirical studies in this dissertation aim to describe how the form and function of learning ecosystems supports the development of naturalists at different spatial and temporal scales. In Paper 2, I consider how adults perceive their environmental interest development across their lifetimes and in different settings. In Paper 3, I zoom in on one program to explore a moment of transition for adolescents as they grow their initial environmental interest into a deeper individual interest that has the beginnings of a naturalist identity.

One of the key findings from Paper 2 was that informal, out-of-school programs often triggered early interest, but didn't often provide the structure for ongoing individual interest development for the study participants. I closed that paper by asking how informal programs might be designed to go beyond merely sparking interest and toward supporting the development of individual interest and a lifelong affinity for science and nature. The need for informal programs to play this role may be less salient where there are other opportunities in learning ecosystems to grow environmental interest, such as parental encouragement or modeling. But, for those youth that may not have as many opportunities to engage with nature, informal education programs have an important role to play in providing more than just exposure. Paper 3 addresses this directly through a case study of an informal science program designed to deepen environmental interest. It looks in real time at the dynamic nature of interest and identity development for adolescents by examining moments of transition as youth deepen their individual interest and grow their environmental identities as naturalists.

Across both studies, mentorship proved to be a critical factor in the development of environmental interest and a naturalist identity. Youth interest development often relies on adult recognition of emerging interests (Heddy & Sinatra, 2017) and the active brokering of additional learning activities by caring adults (Bell et al., 2013; Ching et al., 2016). This often takes the form of parental involvement, which has been shown to predict engagement in organized, voluntary activities such as out-of-school programs (Anderson, Bohnert, & Governale, 2018; Barron, Martin, Takeuchi, & Fithian, 2009). The Youth Naturalist case study provides an example of how an informal program can be structured deliberately to support mentored experiences for youth regardless of family engagement with nature.

Over the course of the summer, I observed the powerful impact that adults had for youth envisioning their future selves as naturalists. In particular, the guest educators, who were all environmental professionals, were regularly referenced by the youth as they talked about their potential futures. This was true even when the adults spent only an hour or two with youth, as I observed in the case of Jeremiah talking about the impact of Abby's bird banding on his ideas for future learning pathways. This suggests that even brief interactions with environmental professionals might positively influence interest development and identity formation.

These interactions were enriched by the program infrastructure designed by the lead educators at the Park organization. For example, Taavi went beyond simply inviting environmental professionals to come in and share information about their line of work. He asked them to present this in the context of actually doing the work, such as data visualization using real data. He also primed the guest educators to think about their personal pathways in advance and then probed them for additional details during their presentations.

In both studies, the mentors functioned as keystones in the learning ecosystem, driving the energy necessary for interest and identity development. This provides an empirical example of a theoretical concept that I introduced in Paper 1 – the potential benefits of focusing on caring adults as keystones in the design of learning ecosystems. Deliberate attention to the design of a learning ecosystem infrastructure, such as mentors as keystones, presents an opportunity to improve youth experiences and interest development in critical subjects such as science and the environment (Penuel et al., 2014).

The two empirical papers also provide examples of how varied environmental interest and identity may be manifest. This is one of the values of the *naturalist* moniker. It is less restrictive and helps to dissolve artificial and unnecessary domain boundaries around what does and does not count as science (Bang & Marin, 2015). For example, I saw Jeremiah's excitement about birds and other nonhuman nature expressed through photography. Eric, one of the adult naturalists, also engaged with nature through his strong photography interest. Daisy, on the other hand, embraced her field journal as a tool to record her ongoing inquiry into moths. This might be more akin to David, the research and applied scientist. And although some orientations might be categorized as artistic, while others might be thought of as scientific, multiple and overlapping orientations can strengthen relational processes between human and nonhuman nature.

The intertwining lines of practice observed in both the life histories and the Youth Naturalist program are indications of the complexity of interest development (Azevedo, 2011). Programs can be designed deliberately to support these lines of practice through the kind of flexible and adaptive infrastructure that I observed in the Youth Naturalist program and which provided varied ways for youth to engage with the environmental content, including stewardship, monitoring, and photography. These two empirical works suggest that use of a learning ecosystem frame, especially one that takes relational processes seriously, may help to describe the complexity of interest and identity development across spatial and temporal scales.

5.3 Learning ecosystems as terra plena environments

In this dissertation, I have examined how conceptual and material elements of Pittsburgh's learning ecosystem are entangled in ways that may help us understand ecosystem function and strengthen environmental interest and identity development. By situating my dissertation work in a specific and named city, I embrace the notion that learning ecosystems are not merely conceptual spaces, but instead include the embodied, material places that we learn in – from classrooms and homes to streets and communities. Attending to the physical places where learning occurs opens up awareness that learning happens not just in the mind, but also in the body (Ellsworth, 2005), and that place itself plays a vital role in learning (Tuck & McKenzie, 2015). In doing this, I hope to draw attention away from learn*ers* and toward learn*ing* by emphasizing how interest and identity come into being through relational processes within learning ecosystems.

Given the powerful role of place on learning in cities, I close with a proposal that, going forward, the design and management of learning ecosystems reject *terra nullius* and colonial logics that too often erase both cultural and natural histories of our urban communities. Instead I propose we adopt *terra plena* – literally meaning a full earth – as a guiding principle for learning ecosystem design and management. The geographer Naomi Miller conceives of *terra plena* as a design ethos where "terra plena thinking articulates meaningful ethical principles for engaging already existing, situated systems of knowledge production" (N. Miller, 2017, p. 104). Therefore, a learning ecosystem that embraces *terra plena* not only recognizes the role of the people and places in homes, schools, and out-of-school – it is specifically designed to honor the value, power and significance that this range of actors bring to learning through their evolving natural and cultural histories (Alim & Paris, 2017).

What might it look like for researchers and practitioners to use *terra plena* as a guiding design principle for learning ecosystems at all scales? This approach to learning ecosystem design connects with a critical place-based approach to learning which contextualizes place within sociocultural history and racial politics (Adams et al., 2017; Gruenewald, 2003). It pushes us to attend to "consciousness of the historical memory of a place, and the tradition that emerged there, whether these have been disrupted or conserved" (Smith & Gruenewald, 2010 as quoted in Bang et al., 2014, p. 42) as essential components of learning ecosystems. Can we intentionally design learning ecosystems in ways that draw on cities' inherent natural and cultural diversity as a strength that can provide infrastructure and support for equitable learning experiences?

The descriptive empirical examples I provide here serve as embryonic ideas for how learning ecosystem infrastructure might be designed to provide healthier and more resilient spaces for environmental interest and identity development. Part of this infrastructure must include taking seriously the urban land and waters, and the human and nonhuman nature that make their homes here, as agential actors in the learning ecosystem. This requires a dissolution of binaries typically enforced by dominant European scientific thought, such as nature/culture, individual/group, epistemology/ontology. Why does this matter for learning? An integrated ethico-onto-epistemology (Barad, 2007) pushes us to think of the learners, educators, and places of a learning ecosystem not as subjects/objects that are connected with each other, but rather as relational elements of an embodied process that are in an ongoing state of becoming (Ellsworth, 2005; McPhie & Clarke, 2015). This approach is deeply grounded in indigenous philosophies (Bang et al., 2014; Bang & Marin, 2015; Kawagley, 2006; Medin et al., 2014; Tuck et al., 2014) and is also reflected in new materialist (Barad, 2007; Fox & Alldred, 2018) and post human philosophies (Haraway, 2016). An important consideration for on-going learning ecosystem research is how scholars, especially those trained in European-derived sciences such as myself, carefully consider and reflect on how these complementary but different ways of knowing might be better integrated in our research approach (Rosiek et al., 2019).

Learning ecosystem framing asks us to approach knowledge production with an ethical responsibility to both the human and nonhuman natural communities with which we are engaged. It is only through this relationality that both humans and nonhuman nature may both become healthier and more resilient in the face of our current environmental crises. This relationality was at the heart of the naturalists' transformative experiences in both of my empirical papers. This is the larger community to be considered in the design of our learning ecosystems. This recognition of our relationality with the nonhuman natural world was evidenced by Ada's reflection that she is not "above" or better than nonhuman nature. It was also present in Charlotte's sense of her role as a steward for the Park land and waters both during her program experience and going into the future. For me, this was manifest over the summer in my own (re)discovery of Park creatures, especially birds that are a growing interest and source of wonder for me. We humans are always becoming ourselves in relation to the land and waters in our midst.

Appendix A Paper 2: Interview protocol

1. Could do talk with me a little about your interest in nature. When did it emerge?
2. Can you describe a little about where you grew up? What kind of neighborhood was it? What kind of community? [country, city, anything unique about that time period]
3. How did nature experiences figure in your experience of those places?
4. How did your family support your interest in nature? Are there specific memories that you have with family members that helped shape your attitude towards nature? [probe re: family structure]
5. [What kind of relationship do your parents have with nature? Are they naturalists? What were their jobs?] [Is nature a unique interest in your family? Intrinsic and personal, vs. familial and contextual?].
6. Did your family do any activities with you that that involved nature?
7. What about activities that happened outside of school. Did anything like museum visits, scouting, camping, field trips, extracurricular activities help support your interest in nature? [Any of those particularly memorable? Pls. explain. As a young child? Older child? Adult. Include all.]
8. Did you do any certificate or workshop type programs as a child that helped advance your interest in nature? (these could include museum-based camps, or certificate programs as an adult, etc.)
9. I'm also interested in the impact of school on your relationship with nature. Can you describe some memorable experiences with nature that you had through school? [glean some info on elementary, middle school, high school]
10. [If not raised yet] What about in college and beyond?
11. Was there someone in your life who was a mentor for you around nature? Tell me about that.
12. I'm curious about how indirect exposure to nature themes might have impacted you. Are there some examples of nature-themed books or TV that stuck with you?
13. Now that you've been thinking through some of these early experiences, can you take a moment to reflect and then describe for me a moment or moments that you'd identify as pivotal - things that either put you on the path towards nature or helped you stay on that path?
14. Is there anything you want to share about your early experiences with nature that we haven't covered?

Appendix B Paper 3: Structured case summary template

Case name (*after nonhuman nature actor***)**:

Overview (*2-3 sentences of why this case was chosen*):

Primary actors:

- **Nonhuman nature**
- **Primary youth:**
- **Secondary youth:**
- **Educator(s):**

Vignettes of youth interest expression through interaction(s) with humans *(include info on interest signal valence here – direct bid v open ended)*

- **Educator**
- **Expert**
- **Youth**

Vignettes of youth interest expression through interaction(s) with nonhuman nature *(include negative valence if presented)*

- **Verbal**
- **Other vocalization**
- **Physical**

Vignettes of youth interest expression through use of naturalist practices

- **IDing/naming**
- **Journaling**
- **Researching**

Educator practices that support youth interest development

Counter evidence for claims of interest

- **Resistance**
- **'Off task' behaviors**
- **Disengagement**

Appendix C Paper 3: Cross case analysis guide

Cross case analysis should reveal youth environmental interest expression as exhibited through the following three types of relational process and interactions: with other humans, with naturalist practices, and with nonhuman nature.

- Read the four cases and think about what evidence there is for each of the three types of interactions. Highlight specific moments or examples in the text, noting which type of interaction is represented using the codes below. Feel free to add additional notes in the margins as needed. Note that the examples I provided below are not exhaustive – feel free to include other things that you notice as well.
    - Interactions with humans, e.g., (CODE = H)
        - Youth envision future selves through contact with environmental professionals
        - Youth express interest after program educators' modeled passion
        - Youth identify as part of a naturalist community after peer interactions
    - Interactions with naturalist practices, e.g., (CODE = NP)
        - Youth write/draw in journals to record ideas and note questions
        - Youth use field guides to deepen knowledge
        - Youth use mobiles apps (Merlin, iNaturalist) for field identification
        - Youth name species (common or Latin names) as form of connection
    - Interactions with nonhuman nature, e.g., (CODE = NHN)
        - Youth have physical contact as an expression of care for the environment, overcoming fear, or developing affinity with creatures
        - Youth observe natural phenomena during which they might be silent or loudly engaged
        - Youth talk with nonhuman nature including naming creatures or talking with them in an effort to connect

- After reading the cases, take a minute to reflect on the following questions.
    - Do the cases ring true? Are there elements that are missing or need adjusting?
    - What surprised you about the cases?
    - What do you want to know more about?

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