Title

The Potential of Place: Leveraging Children’s Local Knowledge and Participatory GIS Mapping to Conceptualize Ecological Systems in Elementary Science Instruction

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by

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Abstract

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Students bring a wealth of resources to science learning contexts, including knowledge of their everyday worlds. Yet within traditional approaches to K-12 science instruction, students typically are not given opportunities to draw upon this knowledge. In this dissertation, I examine the potential of place-based science curriculum and a digital mapping tool to support students' conceptually rich science learning by leveraging their local knowledge.

Through design-based research, I developed an 18-lesson sequence and then analyzed 27 fifth graders' participation within it to examine the potential of place-based science inquiry. Key features of the lesson sequence included (a) students' use of a participatory geographic information system (GIS) mapping tool, *Local Ground*, to support investigating an ecological system - life underfoot on their schoolyard, and (b) students' engagement in disciplinary practices of soil ecologists (e.g., observation at field sites, isolating and measuring variables, aggregating and visualizing data, and generating evidence-based arguments) to further support their understanding of both science knowledge-building practices and ecological systems.

Analyses of student dyads' GIS map use in whole class presentations revealed that the map often afforded students opportunities to integrate their everyday knowledge with data collection experiences in sensemaking. Specifically, the map supported students as they drew upon data generated at different sites and different moments in time as they conjectured and contested arguments about relations between variables like soil moisture, earthworm counts, and shade, digging deep into student-generated data and reasoning about complex ecological relationships and processes.

Longitudinal analyses of two focal dyads over the 18 lessons revealed that student's desires, their emergent affect-laden goals, shaped how they engaged in science disciplinary practices. Students' desires sometimes led them deeper into reasoning about ecological systems and closer into alignment with ecologists' sampling and representational practices, and sometimes led them further away. In contrasting the two pairs' experiences within the same curriculum, this analysis offers insights into how science practices may become needed in formal science contexts.

This dissertation examines the potential of new forms and contexts to support conceptually rich science learning opportunities. This research contributes to the fields' understanding of how we might engage students in science disciplinary practices, in ways that productively build on children's extensive experiences, affect-laden goals, and varied perspectives.

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Chapter 1
Introduction

Fourth graders Kai and Lety dig in an unpaved part of their schoolyard, counting earthworms and other crawling invertebrates they have unearthed. They have measured the soil's compactness, timing how long it takes for water poured into a bottomless tin can to be absorbed, jotting notes and questions. The students are not alone in their field research; other classmates gather similar information at different schoolyard sites. Soon the class will come together, aggregating data into a digital Geographical Information System (GIS) map that depicts each site and its associated data. In addition to exploring patterns using this new representation with their classmates, Kai, Lety, and their peers will be encouraged to hypothesize about potential causal relations between their measured variables. The students will puzzle and reason about observed patterns, drawing upon experiences at their own respective site and their broader everyday experiences on the school grounds.

Kai, Lety[1], and their classmates are engaged in a strikingly different set of activities than one might expect. In most elementary science classes, students are rarely asked to explore the natural world around them, to generate data sets, to search for patterns in data, or to make and evaluate conjectures about underlying causal processes, processes at the crux of scientific inquiry (Latour, 1999; Lehrer & Schauble, 2012; Kathleen E Metz, 1997). If complex ecological systems are broached, children are often asked to reason about distant locales far removed from children's often rich knowledge of the living organisms and places central to their daily lives. In these cases, computer simulations or existing data sets where the context and methods undergirding the data become obscured. These common approaches to science instruction create dual disconnects - from both the knowledge-building practices of science and students' experiential knowledge rooted in everyday contexts.

The Next Generation Science Standards (NGSS Lead States, 2013), developed by a consortium of 23 states from recent consensus documents (National Research Council, 2012)conceptualize K-12 science education in a fundamentally new way, shifting it closer to what Kai and Lety experience. The NGSS aim for students to understand core disciplinary ideas (e.g., interdependent relationships) and crosscutting science concepts (e.g., systems) through engaging in the larger scientific practices of constructing, sharing, and contesting representational forms (often referred to as "modeling"). Through participating in these practices, students are expected to develop deeper conceptual understanding of core scientific concepts, as well as critical appreciation of how science knowledge is socially constructed, critiqued, and revised through modeling activities (Duschl, 2008; Lehrer, Schauble, & Lucas, 2008a; Manz, 2015b).

Yet the uptake of NGSS within state science curriculum presents several conceptual and pedagogical challenges that have only begun to be explored in research. One central challenge is how to design curricula that leverage students' rich and varied experiences beyond the classroom walls. Given the prevailing model of "classrooms as containers" (Leander, Phillips, & Taylor, 2010) cut off from students' everyday knowledge of people, other organisms, and places central to their daily lives, a pressing question remains how to design science curriculum that meaningfully leverages these resources (Barton & Tan, 2009). A second challenge, revealed in

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[1] All student and teacher names are pseudonyms

design-based research projects on students' scientific modeling (e.g., Lehrer & Schauble, 2012) is that students often struggle to integrate their everyday experiences with symbolized abstractions of related phenomena, where such integration is central to science theory building (Giere, 1997; Latour, 1999). This integration is especially challenging if children are less familiar with the phenomena of study, the representational forms they are using (e.g., bar charts, two-way tables), or the process of moving between the phenomena and the associated representational forms (Roth, Pozzer-Ardenghi, & Han, 2005). A third central challenge is how to design science curriculum and digital tools, in ways that foster a *need* for science practices, not simply a rehearsal or copycat enactment. Given the practice-turn (Ford, 2015) in science education research and teaching, it is crucial to understand *how* students come to engage in and sustain this engagement in science practices in classroom contexts (Jaber & Hammer, 2016b; Manz, 2015a).

Participatory Geographical Information System (GIS) mapping tools have shown the potential to support youth in integrating their first-person experiences in everyday spaces as they reason with complex data about larger complex systems and processes (Rubel, Hall-Wieckert, & Lim, 2017; Headrick Taylor, 2017; Headrick Taylor & Hall, 2013). Recent research has documented powerful ways in which participatory GIS mapping can foster both critical conceptual learning and new forms of participation by supporting youth in collecting, visualizing, and reasoning with data about the places and people central to their daily lives. Existing work in this field has focused on mathematics and social justice (Enyedy & Mukhopadhyay, 2007; Rubel, Lim, Hall-Wieckert, & Sullivan, 2016), civic planning and engagement (Headrick Taylor & Hall, 2013; Van Wart, Tsai & Parikh, 2010) and social studies and political engagement (Mitchell & Elwood, 2012), primarily with middle school and high school aged students. Yet to date, there has been only nascent work focused on how these interactive GIS mapping technologies might be used by elementary aged students, particularly integrating younger student's everyday experiences beyond the classroom walls and rich engagement in science disciplinary practices.

In my dissertation, I take up these challenge and opportunities. I draw on design-based research methodologies to investigate the potential of place-based science inquiry practices and a digital GIS mapping tool, *Local Ground* to support children's movement between their everyday knowledge, data, and explanation. Working with one 5th grade class (n =27) over several months at a public elementary school, I designed, taught, and researched an 18-lesson spiraling curriculum that supported students as they engaged in approximations of ecologists' practices to study a local ecological system, the soil ecology underfoot in their schoolyard. Students engaged in two cycles of ecologists' practices, including identifying parts of an ecological system, transforming parts of the system into variables, and aggregating values of variables into different forms of representation supported by the GIS mapping software. The GIS mapping software also supported the students' collection of qualitative data such as sketches and narratives about their sites. After each cycle, students used the aggregated data to analyze relationships between variables, and engaged in argumentation about causal explanations.

Dissertation Structure

In the chapters that follow, I describe my methodological approach to address these central challenges in K-12 science instruction. I then describe the two lines of analysis that engage these challenges, examining the possibilities of place-based science and participatory GIS maps to support conceptually rich science learning opportunities. I conclude with discussions outlining major findings and promising directions for future work.

In the second chapter, *Design Based Research Approach: Principles and Design*, I describe my methodological and theoretical approach to design-based research. I outline the guiding design principles and conjectures, situating them within related research literature in science education, learning sciences, and science and technology studies (STS) fields. I describe how I used these principles in the design and re-design of the multi-week curriculum integrating the GIS mapping tool *Local Ground* into students' study of an everyday ecological system.

In *Methods,* the third chapter, I outline my methods of research, including the research setting and participants. I describe the data, including their sources and how they were collected at varying scales of activity (whole class, dyad, individual) to provide multiple lenses for studying students' interactions and learning over time and across contexts (inside, outside, digital representations).

This theoretical and methodological work sets the stage for my two empirical lines of analysis. In *Participatory GIS Maps in Elementary Science Inquiry and Argumentation: Coordinating Everyday Knowledge of Place and Data in Collective Discussion***,** the fourth chapter, I present my first line of analysis. I examine how students coordinated and leveraged their everyday schoolyard knowledge and the experiences of collecting and transforming data as they conjectured and contested explanations about ecological relationships and processes using the GIS maps. Analyses of select whole class discussions reveal that the interactive GIS maps were often an important resource that afforded students generative sense-making opportunities to coordinate their individual and aggregate observations, experiences, and measurements as they engaged in reasoning about relationships and explanations of everyday ecological systems. At the same time, despite the affordances of the GIS maps, analyses reveal instances in which the map showed limited utility, and students produced other representational forms to support argumentation with the map setting a context but backgrounded in student argumentation. These findings contribute to existing accounts of learning with digital spatial tools. They also offer insights into how such tools come to be used by elementary students as they engage in science disciplinary practices of argumentation, in ways that support complex reasoning with data and integrating of everyday experiences.

In the fifth chapter, I present my second line of analysis, *Elementary Students' Engagement in Science Practices to Support Systemic Inquiry: Clash and Confluence Rooted in Students' Desires*. Here I examine emergent tensions between the curriculum, which was designed to engage students in approximations of ecologists' practices, and students' own desires (Pea, 1993) as they emerged in interactions with classmates, the schoolyard space, and representational forms. Through longitudinal analyses of whole class video, dyad video, student and teaching artifacts, and semi-structured interviews, I examine two student pairs' experiences across the two cycles of science practices. I find that children's desires sometimes led them deeper into reasoning about ecological systems and closer alignment with ecologists' sampling and representational practices, and sometimes pushed them further away. By contrasting the two pairs' experiences across time within the same curriculum, this analysis offers insights into *how* science practices may become needed (Manz, 2015a) in elementary K-5 contexts. It also provides insights into the generative heterogeneity of children's learning experiences with classroom contexts).

In the sixth chapter, *Discussion and Future Research,* I reflect on the methodological approach and empirical results presented in this dissertation, in terms of their implications for understanding younger students’ engagement in disciplinary practices in ways that leverage their experiences and perspectives. I discuss themes across the empirical chapters and implications for K-12 science practice and learning theories. I conclude by discussing limitations of this dissertation research and promising future lines of research.

Chapter 2

Design-Based Research Approach: Principles and Design

This dissertation reports on the most recent iteration of a larger design-based research study. This study focuses on the potential of place-based science pedagogy and participatory GIS mapping tools to support elementary students' learning about ecological systems. In this chapter, I describe the methodological approach I used to design and redesign the 18-class session curriculum. I begin with a brief overview of design-based research approaches. I then outline my design principles and describe how these principles were instantiated within the multi-week curriculum.

Design-Based Research: Theoretical and Methodological Approach

Design-based research is an iterative approach to educational research that aims to refine, elaborate, and produce new theories, artifacts, and practices through the design of innovative learning opportunities (Cobb, Confrey, Lehrer, & Schauble, 2003; Sandoval & Bell, 2004) As Sandoval (2014) writes, "Design research is defined mainly in terms of certain epistemic commitments that include, among others, the joint pursuit of practical improvement and theoretical refinement; cycles of design, enactment, analysis, and revision; and attempts to link processes of enactment to outcomes of interest" (Sandoval, 2014, pg. 19). This approach to research often involves sustained relationships working closely with teachers and schools, with concerns for shaping both new forms of practice and theories of learning.

Design Principles

In this dissertation, the instructional design was informed by four top-level design principles, all with the purpose of supporting students' learning about ecological systems, including:

1. Situate student's science inquiry within everyday local contexts integral to their daily lives
2. Create multiple opportunities for students to create and critique data
3. Engage students in science disciplinary practices to support conceptual, epistemic, and social learning opportunities
4. Explore data at varying levels of abstraction and scale, with participatory GIS maps as a central form

These principles are described in further detail in the following section, followed by a description of the instructional design summarized through the lens of these four principles.

Design principle #1: Situate students' science inquiry within everyday local contexts integral to their daily lives. Within the learning sciences and science education research fields, scholars have argued that situating science inquiry in children's everyday spaces and places can support powerful science learning opportunities. One line of research focuses on the potential of everyday spaces to support instigation of science disciplinary practices and rich science reasoning. Using overgrown spaces behind a school or nearby streams, researchers argue that such everyday contexts provide a requisite materiality and complexity that supports authentic science knowledge-building practices such as modeling and argumentation (Cotterman, 2016; Forsythe, 2018; Lehrer & Schauble, 2017; Manz, 2015b, 2016). Scholars argue that rigorous conceptual, epistemic, and social learning opportunities can be supported through students' physical and representational movement between outdoor complex ecological systems and smaller models of these systems within classrooms.

A second line of research focuses on students' everyday knowledge and experiences central to their daily lives as a resource for robust science reasoning. Scholars argue that students' social, emotional, cultural, and kinesthetic experiences are generative resources often overlooked in traditional science classrooms (e.g., Lim & Barton, 2010). In several studies, researchers have examined how students' heterogeneous experiences beyond the school walls can become powerful resources in supporting rich and critical science argumentation in classroom contexts (Barton & Tan, 2009; Rosebery, Ogonowski, Dischino, & Warren, 2010).

In my research design, I sought to build on these two lines of research by centering students' inquiry on a complex socio-ecological system - their own local schoolyard. This context offered a complex and material context for studying ecological systems and instigating science disciplinary practices. It was also a place that children knew across multiple modalities (e.g., social, emotional, kinesthetic) and time scales (e.g., daily, seasonal, annual). In leveraging two major lines of place-based science education research, I aimed to foster rich conceptual learning opportunities and expand what ways of knowing could be integral to students' science reasoning and argumentation.

Design principle #2: Create multiple opportunities for students to create and critique data. Within classroom communities, it is important for students to have multiple opportunities to be both authors and readers of data to help them see the socially constructed nature of data representations (Greeno & Hall, 1997). By both constructing and critiquing relationships and explanations using multiple data forms, students gain not only conceptual but also epistemic insights into the science discipline. Scholars have argued such a dual perspective is key for fully leveraging children's metarepresentational competence (diSessa, 2004). This dual perspective can also foster youth's critical perspectives on data's inherent strengths and limitations(Roth et al., 2005).

However, such activity depends on developing norms and routines that support creation and critique, with an eye towards supporting student explanations using data. This involves developing collective practices for supporting sharing, contesting, and building on others' ideas across a range of social configurations. Social groupings often involve shifting between initial work in pairs wherein students have more autonomy and collaborative responsibility (e.g., Metz, 2011) to small group and whole-class discussions where children are likely to encounter discrepant recordings and varied interpretations of data (Lehrer et al., 2008a; Manz, 2016).

In my research design, I created multiple opportunities and social contexts for students to use their data to conjecture and contest relationships and explanations. I designed for dyad pairs to be a core unit of activity in the classroom for initial site selection, data collection activity, and sense making with the initial aggregated data. This dyad-level activity was balanced in each class with opportunities for small group discussion and whole class activities. At the whole class level, students collectively constructed multiple representational forms using their aggregated data, including canonical (e.g., two-way tables, bar charts) and map based representations (paper and digital data maps). I also fostered a particular collective practice (Saxe, 2012) of research meetings (e.g., Lehrer, Schauble, and Lucas, 2008; Manz, 2016). These meetings supported whole-class conjecturing and contesting relationships in the aggregate data using multiple student-created representational forms.

Design principle #3: Engage students in science disciplinary practices to support

conceptual, epistemic, and social learning opportunities. Scholars argue that children's engagement in science disciplinary practices can support conceptual, epistemic, and social aspects of science learning (Manz, 2012; Metz, 2004; Metz, 2011; Stroupe, 2015) This 'practice turn' (Ford, 2015) is reflected in recent consensus documents (National Research Council, 2012; NGSS Lead States, 2013) contain calls to engage K-12 students in science disciplinary practices (e.g., posing questions, developing and using models, planning and carrying out investigation, interpreting and arguing with data). In addition to conceptual and epistemic benefits, scholars also point to the potential benefits of shifting the authority and agency of learning towards students (Basu & Barton, 2007; Engle, R. A., & Conant, 2002; Lemke, 1990).

In my study design, students' engagement in approximations of ecologists' practices was integral to their learning about ecological systems. I drew on classroom-based design research and science and technology studies literature of ecologists' to support ecology-specific practices in elementary school contexts. Ecologists' practices included identifying parts of the ecological system (e.g., refining research questions and identifying potential variables), transforming parts into variables (e.g., selecting sampling sites, collecting multiple types of data) and aggregating, visualizing, and explaining data (e.g. creating and contesting varied representational forms, with a focus on conjecturing and contesting potential relationships and explanations in the data). By engaging in two cycles of ecologist' practices, students were supported in engaging in the conceptual, epistemic, material and social dimensions of science disciplinary practices.

Design principle #4: Explore data at varying levels of abstraction and scale, with participatory GIS maps as a central form. Central to "doing science" is modeling, an iterative, social process of transforming the complex, material world into symbolized forms to build and refute theory (Giere, 1997; Latour, 1987; Pickering, 2010). By engaging in this process of amplification and reduction of phenomena through inscriptional means (Latour, 1999), scholars argue that students are supported in developing deeper conceptual and critical perspectives, as well as developing facileness in both interpreting and critiquing abstracted data forms (Roth et al., 2005). To support younger students in these activities, researchers have paid careful attention to supporting progressive symbolization from material to abstracted forms (Penner, Giles, Lehrer, & Schauble, 1997) involving gradually increasing quantities and symbolization of data as well as shifting cartographic perspectives (Enyedy, 2005a; Radinsky, 2008).

Participatory GIS maps are a potentially powerful digital tool to support students' movement between everyday phenomena and their reasoning about complex systems and processes in aggregated data (Enyedy & Mukhopadhyay, 2007; Rubel et al., 2017). Participatory GIS mapping tools support youth gathering data in multiple forms (sketches, photos, audio, video, text, numerical) and formats (paper maps, digital maps). Working with this mix of qualitative and quantitative data, it is possible for youth to explore patterns at many scales (e.g., street, neighborhood, city) and volumes (e.g., by variable, by site, by data type). Recent work has spanned ages and school disciplines (e.g., Kornbluh, Ozer, Allen, & Kirshner, 2015; Ranieri & Bruni, 2012; Taylor & Hall, 2013; Van Wart & Parikh, 2013). Yet to date, these GIS mapping tools remained understudied with younger students and in science disciplines (K.A. Lanouette, Van Wart, & Parikh, 2016).

In my study design, a central component of the curriculum was that students were engaged in iterative rounds of creating and exploring data in varying levels of abstraction and scale. *Local Ground* (Vart Wart & Parikh, 2013), a participatory GIS mapping tool, was a central representational form throughout. It was used to support students in creating and using a wide range of their student-generated data formats (e.g., photos, text, sketches, numerical counts) as they conjectured and contested relationships and explanations in their classes' aggregated data.

Design Iterations: Iteration I and II

In line with design-based research approaches (Cobb et al., 2003; Sandoval & Bell, 2004), I iteratively developed and refined two curricular sequences occurring in the 2014-2015 and 2016-2017 school years. In doing so, I considered conjectures about students' reasoning about ecological systems, their coordination of their everyday schoolyard knowledge and engagement in science disciplinary practices, and the role of the *Local Ground* maps in classroom activities.

Across both iterations, I collaborated with an urban public elementary school, working directly with the school's science teacher. In the 2014-2015 school year, Sarah Van Wart and I co-designed and co-taught one 4th grade class (n=24) using an early version of *Local Ground* with support from Dr. Tapan Parikh. This research occurred across eight weeks and included 10 class sessions ranging from 45 to 90 minutes each. In the 2016-2017 school year, I took the lead as designer, teacher, and researcher, and worked with Sarah Van Wart and her design team on revisions to *Local Ground*. Across ten weeks, I worked with one 5th grade class (n=27) as they engaged in two waves of gathering data in their schoolyard using a redesigned version of *Local Ground*. This research spanned across 18 class sessions, ranging from 45-90 minutes each.

Similar to Manz's descriptions of her design research process (Manz, 2016), I developed and refined conjectures about student reasoning about ecological systems, *Local Ground* map use, and use of their everyday schoolyard knowledge. This process of developing and refining conjectures occurred across iterations and within the most recent iteration itself.

Iterations across designs. Experiences in the first iteration (2014-2015) guided the curricular and tool design entering into the second iteration.

Curricular design iterations. In the first iteration, students engaged in one cycle of collecting data at their schoolyard sites. Yet this one cycle limited students' ability to explore questions emerging in their class data, much as practicing scientists do. As a result, in the second iteration, I supported students' engagement in two cycles of ecologists' practices of data collection and visualization. Additionally, in the first iteration, sampling sites were pre-selected by myself to ensure variability in sampling site characteristics (e.g., ranges in organisms, soil characteristics) and limited to a smaller sub section of the schoolyard. In the second iteration, I let students' select two sampling sites from across the entire schoolyard. By doing so, I aimed to support increased student autonomy. I also sought to gain insights into what aspects of the schoolyard system students considered in selecting sampling sites and how students' considerations of multiple parts of the ecological system might shift between cycles of data collection and visualization. (See Table 1 for design iterations).

Tool design. In interacting with the *Local Ground* interface during the first iteration, students encountered challenges comparing data at different sites and navigating between different data types (e.g., photographs, sketches, text notes, symbolized data). In response, the *Local Ground* design team redesigned the map interface to support multi-site comparisons and create two levels of data in order to make the varied data types more organized and accessible. There were also promising uses of the *Local Ground* interface during the first iteration. During whole class discussions, students used the maps to weave together multiple types of data and their schoolyard experiences as they quickly created and contested different configurations of their data (see Lanouette, Van Wart & Parikh, 2016 for analyses of these whole class discussions during the first iteration).

Iterations within design. Conjectures were also refined within the iteration itself. In the 2016-2017 school year, this iterative work occurred through weekly reflection meetings with the science teacher and the 5th grade teacher, where we discussed students' work, their use of the *Local Ground* maps, and their engagement in the curricular activities. There also were weekly meetings with my research assistant, Jazmin Garcia, where we discussed students' activities during that week's lesson as well as teaching and student artifacts collected. Lastly, there were bi-weekly meetings with the *Local Ground* design team lead by Sarah Van Wart and included designers Riley Flynn and Karin Goh. In these meetings, we discussed the design of the *Local Ground* mapping interface and troubleshooted any technical glitches in the GIS mapping software.

Table 1
Design Iterations of Curriculum and Local Ground maps

	Iteration I (2014-2015)	Iteration II (2016-2017)
Curriculum	4th grade class, Fall 10 class sessions Researchers select sampling sites 1 cycle of ecologist's practices Digital map progression	5th grade class, Winter and Spring 18 class sessions Students select sampling sites 2 cycles of ecologists' practices Paper to digital map progression, including several canonical data formats
Local Ground Map Technology	Initial mapping interface made it challenging to (a) access different data layers and (b) compare two or more sites	Revised interface to create two distinct layers for data to (a) support accessing and organizing different layers and (b) compare multiple sites and variables simultaneously

Curricular Design

Based on these four design principles and the observations, findings, and questions that arose during the project's first iteration, I developed a ten-week soil ecology curriculum that engaged children in participatory mapping of the local schoolyard during the winter and spring months. Between January and April 2017, 18 lessons were conducted. They occurred twice weekly during the classes' regularly scheduled morning science classes and lasted between 45-90 minutes each (see Table 2 for overview of 18 class sessions).

Table 2

Curriculum Summary, showing ecologists' practices, instructional activities and shifting representation forms

	Ecologist's Practices	**Instructional Activities of Teacher and Students**	**Representational Forms**
Cycle I	*Identifying Parts of System* * Define research agenda, including refining questions and potential variables *Begin to differentiate parts of ecological system and consider potential relationships	*Lessons 1-4* *Teacher poses initial questions, of "What is underfoot?" and "How might these parts be connected?" * Students begin to identify and differentiate parts of schoolyard socio-ecological system, voicing different rationales for parts and potential relationships *Teacher sorts initial parts list into living/ non living and above/ below ground lists *Students generate initial list of sites for begin studying parts and potential relationships, visiting potential sites *Students select initial sites for sampling	Color Photograph Map
	Transforming Parts into Variables *Observation and measurement at selected sites to examine variation and covariation in larger ecological system	*Lessons 5-6* *Teacher leads discussion of potential data collection tools and techniques, posing question of "How can we find out more?" *Students decide on final sites for sampling *Students collect data at sites, including initial site observations outside, soil moisture, soil texture, soil compaction, invertebrate counts (including specifically earthworms), above ground activity and any additional data they think would be helpful for understanding the system, its parts, and interrelationships.	Field Notes, including photographs, sketches, text notes, and numerical counts
	Aggregating, Visualizing and Explanation * Identify and reason about patterns of co-variation in the ecological system and conjecturing possible explanations	*Lessons 7-12* *Students aggregate all their data using multiple representational formats to begin exploring patterns of variation and covariation in the ecological system * Research Meeting (Lehrer, Schauble & Lucas, 2008) involving students constructing, sharing and contesting patterns in data * Emergent discussions about reliability of methods and resulting data related to temporal and spatial aspects of sampling	Paper Data Maps Digital Data Maps Bar Charts Two-Way Tables
Cycle II	*Identifying Parts of System* * Refining questions, variables and methodologies in response to earlier findings *Further differentiate parts of ecological system and consider potential relationship	*Lesson 13* *Teacher leads discussion of potential data collection tools and techniques, posing question of "How can we find out more?" * Students plan and select second site, with student pairs deciding between returning to the original site or selecting a new site	Digital Data Map
	Transforming Parts into Variables *Observation and measurement at selected sites with select variables to examine variation and covariation in larger system	*Lessons 14-15* *Student collect data at original site or new site, including soil moisture, soil texture, soil compaction, invertebrate counts (including specifically earthworms) and above ground activity	Field Notes, including photographs, sketches, text notes, and numerical counts
	Aggregating, Visualizing and Explanation * Identify and reason about patterns of co-variation in the ecological system and conjecturing possible explanations	*Lessons 16-18* *Students aggregate data at whole class level, generating bar charts and interactive GIS maps to examine variation and co-variation to reason about underlying mechanisms * Research Meeting (Lehrer, Schuable & Lucas, 2008) involving constructing, sharing and contesting patterns in data as well as revising research questions and methods	Digital Data Maps (Local Ground)

Below, I describe the process for selecting the students' schoolyard as a context for studying ecological systems. I then describe the *Local Ground* mapping tool and its functionalities. Next, I describe the overarching question framework that guided classroom activity and meta-level processes of engaging in science disciplinary practices. I conclude by discussing the specific social configurations structured to support students' sensemaking.

Selecting soil ecology and the schoolyard. In selecting a focal context for the curriculum, I considered how best to leverage students' everyday knowledge from their daily lives and support reasoning about complex ecological systems. Students' own schoolyard and the soil ecology underfoot were generative for these purposes for several reasons. First, the schoolyard was a place that students knew well from their everyday experiences. This knowledge encompassed multiple modalities (e.g., kinesthetic, affective) and spanned across several years. As such, students brought with them a varied and rich knowledge of the plants and animals therein as well as humans' uses of the schoolyard. Second, there was substantial variation in the schoolyard soil ecosystem at multiple levels. At a micro level, there were noticeable differences below ground in soil composition, sunlight and shade, invertebrate populations, and human activity, often just feet apart. At the level of the entire schoolyard, the space was used above ground in a variety of ways (e.g., sports grass field, asphalt black tops, play equipment, school garden). This resulted in a wide range of human activities (e.g., high traffic locations during morning pledge, basketball playing, puddle stomping during the rainy season) and environmental conditions (e.g. shifting sunlight and shade patterns across the day and the year, specific areas prone to seasonal flooding). In ecological research, studying complex ecological systems involves identifying and coordinating multiple interacting micro-level and macro-level parts and processes across varying time scales and locations. Some parts of the system are readily visible and tangible (e.g., crawling invertebrates, soil composition) while others require special tools and techniques to see (e.g., soil PH, soil infiltration/ compaction). Yet such coordination work across levels is central to students' understanding of ecological systems and intertwined concepts such as natural selection, evolution, and climate change (Lehrer & Schauble, 2012; Metz, 2011). As such, students' schoolyard and the soil ecosystem underfoot offered an ideal context for leveraging student's everyday knowledge and reasoning about a complex ecological system.

To design the curriculum, I drew on two resources. One resource was the cooperating teachers in the project, the elementary science teacher and the 5th grade homeroom teachers. In our summer and early school year meetings, both teachers offered feedback on the design of the second iteration curriculum. They provided important information about the history of the schoolyard space, such as recent schoolyard renovations, and their students' own experiences and interests. Additionally, they were eager to support science learning rooted in action, where students could be "doing science" and their work could have meaningful implications within the school community. These conversations shaped both my curricular design and instructional approach. Second, I drew on existing research classroom design-based research supporting elementary aged children learning about ecological systems (Kissling & Calabrese Barton, 2015; Lehrer & Schauble, 2012; Lehrer, Schauble, & Lucas, 2008b; Manz, 2015b).

Framework questions. The curriculum centered around five central questions (see Table 3). These questions were intended to anchor instruction around meta-level science inquiry processes. Initial questioned problematized (Dewey, 2007; Phillips, Watkins, & Hammer, 2018) the physical space and encouraged students to considering the different parts and interrelationships of the system. Later questions raised attention to method selection and explanation. The last question supported students considering potential recommendation they might make based on their findings. These five questions functioned as frames for specific lesson's purpose. For example, individual lessons often focused on one or two questions only. These five questions also served as a potential bi-directional progression in student reasoning supported by the 18-lesson curriculum, shifting students' considerations of *What is there?* towards *How can we know?* towards *Why might this be?* and *What can we do…?*

Table 3
Curriculum Framework Questions and Related Functions

Framework Questions	**Functions of Questions**
What is underground?	Problematize everyday underground spaces, supporting consideration of what they do and do not know about the soil underfoot
In what ways are the different parts connected?	Elevate considerations of different parts of system and interrelationships between parts, including living and non living parts
How can we find out more?	Motivate sampling methodologies and attending to potential threats to validity
Why might this be?	Encourage conjecturing explanations about relationships among parts
What can we do in our school community?	Use data and emergent relationships to suggest land use changes in schoolyard

Cycles of ecologists' practices. To support children's learning about ecological systems, students engaged in two cycles of ecology-specific disciplinary practices (see Figure 1). These included identifying parts of an ecosystem, transforming parts into measurable variables involving collecting, aggregating, and visualizing, and explaining their data in partner and whole class discussions. In defining these practices, I drew on two sources in the design process, including science and technology studies' depictions of ecologists' practices (Bowen & Roth, 2007; Cotterman, 2016; Latour, 1999; Pickering, 2010) and design-based research supporting children's reasoning about ecological systems (Forsythe, 2018; Kissling & Calabrese Barton, 2015; Lehrer & Schauble, 2012; Lehrer et al., 2008a; Manz, 2015b) (see Chapter 5 for a more extended discussion of ecologists' practices).

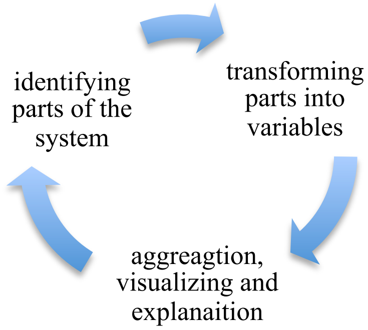
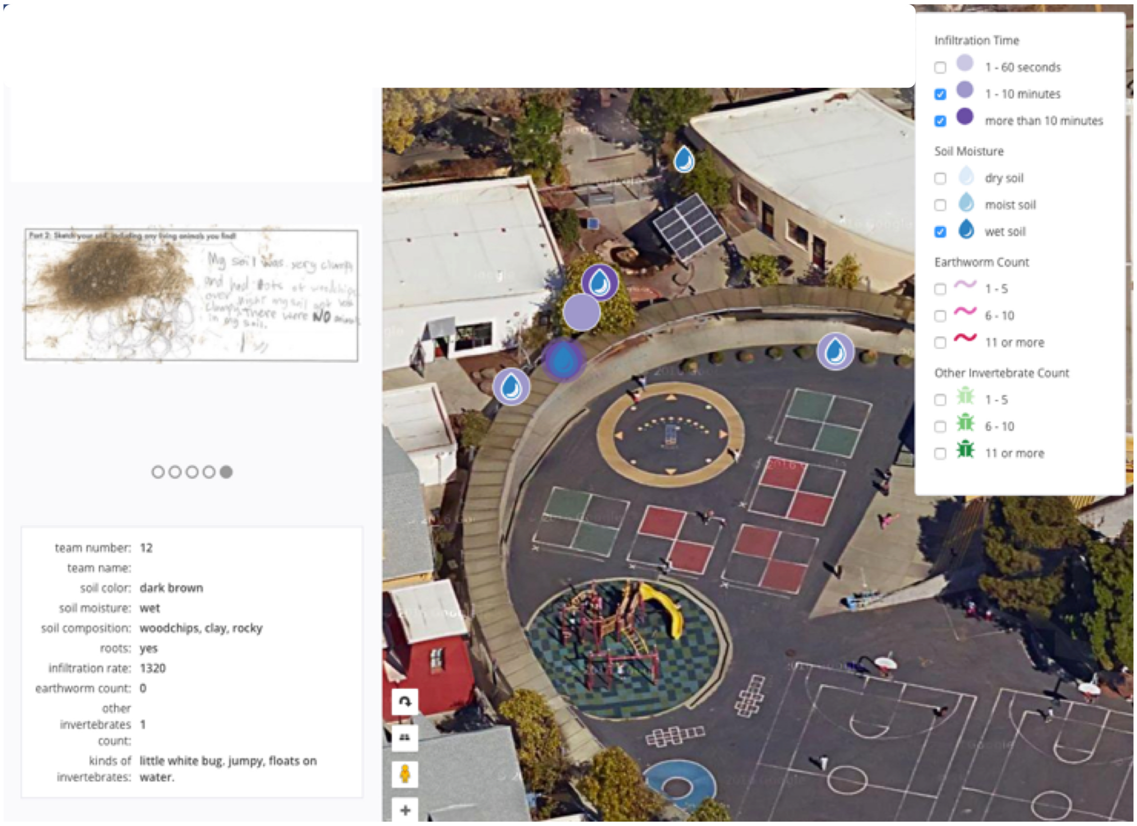


Figure 1. Cycle of Ecologist' Practices, adapted from Cotterman (2016)

Participatory Mapping Tool (*Local Ground*)

Across the curriculum, students frequently worked with their data using an interactive mapping platform called *Local Ground* (Van Wart & Parikh, 2013). This tool is an online mapping and data visualization platform that provides youth opportunities to learn and use data science skills in support of local civic engagement and citizen science projects (see Figure 2). *Local Ground* allows learners to (a) collect locally relevant data, including as hand-drawn map annotations, unstructured images and audio, and handwritten tables; (b) enter, tag, and geo-reference this raw data into a usable digital format; (c) explore and visualize this data, using spreadsheet and map formats; and (d) create narratives from multimedia data to be presented and shared with others.



team number:	12
team name:	
soil color:	dark brown
soil moisture:	wet
soil composition:	woodchips, clay, rocky
roots:	yes
infiltration rate:	1320
earthworm count:	0
other invertebrates count:	1
kinds of invertebrates:	little white bug, jumpy, floats on water.

Infiltration Time
☐ 1 - 60 seconds
☑ 1 - 10 minutes
☑ more than 10 minutes

Soil Moisture
☐ dry soil
☐ moist soil
☑ wet soil

Earthworm Count
☐ 1 - 5
☐ 6 - 10
☐ 11 or more

Other Invertebrate Count
☐ 1 - 5
☐ 6 - 10
☐ 11 or more

Figure 2. Local Ground Map interface, showing students' data in multiple formats (text notes, sketches on the let) and categorical data on the right hand side.

Shifting map forms and uses. Students' use of the maps shifted across the different cycles of practices, in the map type (paper to digital), the amount of data (e.g., one variable, multiple variable), and the type of data (e.g., numerical counts, text, photos). These shifts were done deliberately to support students familiarizing themselves with the bird's eye view of the schoolyard offered by maps. The shifts were also enacted to support a gradual increase in the volume and level of abstraction of the data students were working with. For example, early on students worked in pairs with a color paper maps covered in plastic, using stickers and expo markers to identify sites of interest inside and walking outside. Students also annotated a large color map in early whole class discussions, using post it notes to share their considered sampling sites. Later, with data collected by all pairs, students constructed color paper maps overlaid with different colored stickers representing different variables. Students also used *Local Ground*'s interactive digital GIS maps that supported organizing and aggregating the classes' multiple data *forms* (sketches, photos, audio, text, numerical data) and *volumes* of data (one variable, several variables). These paper data maps and digital data maps were created collectively and used in whole class, dyad, and individual contexts. Throughout their work with multiple map forms, students also created and worked with more canonical data forms, such as two-way tables of their invertebrate count data and bar charts of one or two variables, by site location. In the last four class sessions, all data forms, including paper and digital maps, as well as two-way tables and bar charts, were made available. (See Table X for shifting progression of map use).

Social Groupings

Social groupings varied across lessons and phases of activity. Early on, children worked closely with one partner in the site selection, data collection, and aggregation phase, working independently together to select sites to study, gather data at their site, record findings on their note sheets, and work together when the class constructed group data forms such as the color sticker map, invertebrate chart, or bar charts. The autonomy of the small dyad was balanced by each lesson starting (and generally ending) as a whole class on the rug, with increasing opportunities for whole group discussion at the end of each inquiry cycle. There were also several lessons where pairs worked together at tables, supporting cross dyad conversations (four children total at the tables). This mix of dyad, small group, and whole class activity structures was designed to provide varied opportunities for students to participating in the science disciplinary practices.

Research meetings were one form of whole class activity supported across both cycles of activity. Building on Lehrer, Schauble, and Lucas (2008), Manz (2016) and Forsythe's (2018) activity structure, these whole class meetings were designed to support students conjecturing and contesting evidence and claims using the classes' aggregated data, with an emphasis on moving towards explanations. During these discussions, pairs raised "patterns and puzzles" in their data, which included relationships they were noting among variables as well as puzzling or unexpected relationships across variables or specific data points. Pairs shared their thinking and their data using the *Local Ground* map interface projected on a larger screen, where presenting pairs and classmates could readily adjust the data as discussions unfolded. The objective was to provide students with distributed access to the classes' aggregated data in argumentation.

Instructional Progression

In the sections below, I describe the two cycles of ecologists' practices supported across the 18 class sessions, highlighting the shifting mapping forms and social contexts in relation to the changing framework questions and related ecologists' practices.

Cycle I of ecologists' practices to support system level understanding.

Identifying parts of the system (lessons 1-4, 4 class sessions). In the first four class sessions, activity focused on the initial questions of "What is underfoot?" and "How might the different parts be connected?" Students started off by brainstorming what they expected to find both above and below ground in the schoolyard. The students brainstormed first in pairs, then together as a whole class, with the teacher recording student ideas on larger chart paper. From this list, I divided the students' original ideas into two lists - living and nonliving. I then asked students to consider site locations where they might be able to study interesting interactions between these two dimensions as well as above and below ground interactions (see Figure 3, showing the teacher generated lists and site selection prompts).

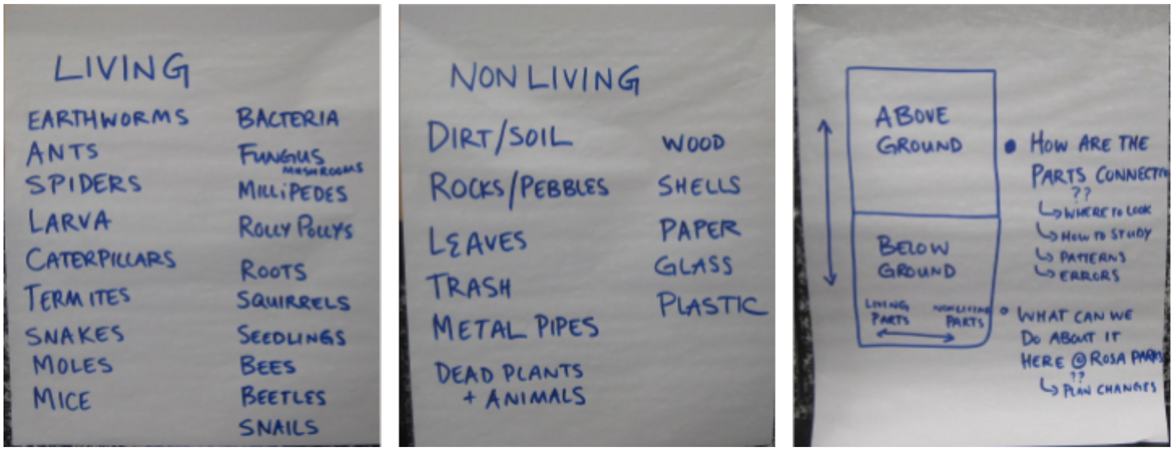


Figure 3. Chart paper showing students' initial ideas of what is underfoot, divided by the teacher into living and nonliving parts of the schoolyard and chart paper prompting students to consider above and below ground interactions among living and non living parts

Using a printed color photograph map of the schoolyard, student pairs then headed outside to walk around and explore the schoolyard, considering potential sites where they might study relationships. Potential sites were marked on their small paper maps with stickers. After returning from the schoolyard, student pairs shared potential site ideas in small groups at their tables using their maps. Students then gathered as a whole class in front of a large color photograph map. Using post-it notes to mark potential sampling sites, students proposed and critiqued different sampling sites (see Figure 4, showing potential sites proposed in the whole class discussion).

Figure 4. Students' initial site selections on a large color paper map (3 ft. x 5 ft.), marked with post-it notes showing a wide range of potential site locations (e.g., school garden, sports fields, blacktop play areas, and outside classroom spaces.

With all pairs having selected their initial sampling sites, the teacher led a discussion of select methods ecologists often use to study soil ecology systems.

Transforming parts into variables (lessons 5-7, 3 class sessions). In the next three lessons, students worked in pairs to collect data at their selected sites on many of the initial ideas the students generated, focusing on the question, "How can we find out more?" Pairs' data included counting and sketching any invertebrates they unearthed at their sites, describing the soil composition (color, texture, moisture) and determining soil compaction by filling a bottomless tin can with water and its absorption into the ground. Students also returned to set pitfall traps, small traps made using plastic cups and cardboard, to capture other invertebrates over longer time durations. Student data took the form of photographs, sketches, and written field notes (see Figure 5).

DATA COLLECTION (DAY 2)

Part 1: Pitfall Traps

Nothing	0
earwig	1
spider	1

Part 2: Infiltration Rate

2:39

Wet & Sunny

Figure 5. Setting pitfall traps, sharing notes, and an example of a student's field notes

Aggregating, visualizing and explaining (lessons 8-12, 5 class sessions). Back in the classroom, pairs worked together to aggregate the data, exploring relationships across the 13 sites and data types using a paper sticker map, an invertebrate chart, sticker bar charts, and *Local Ground*'s digital map. Activity centered on the framework questions of "Why might this be?" and "What can we do about it in our school neighborhood?" Students were involved in creating all representational data forms, from posting initial earthworm counts at their sites and constructing a bar chart of the same earthworm and soil moisture data, to constructing multivariate paper data maps with stickers, and creating digital maps using *Local Ground* (see Figure 6, a-e). With all forms, there was extended discussions in pairs, small groups, and whole group contexts, including the first Research Meeting using the *Local Ground* maps. In this meeting, students shared patterns they noticed in the aggregated data forms and discussed potential explanations about above ground and below ground interactions. Discussions also centered on potential land use suggestions students might make to the principal, based on their initial findings and mapping work.

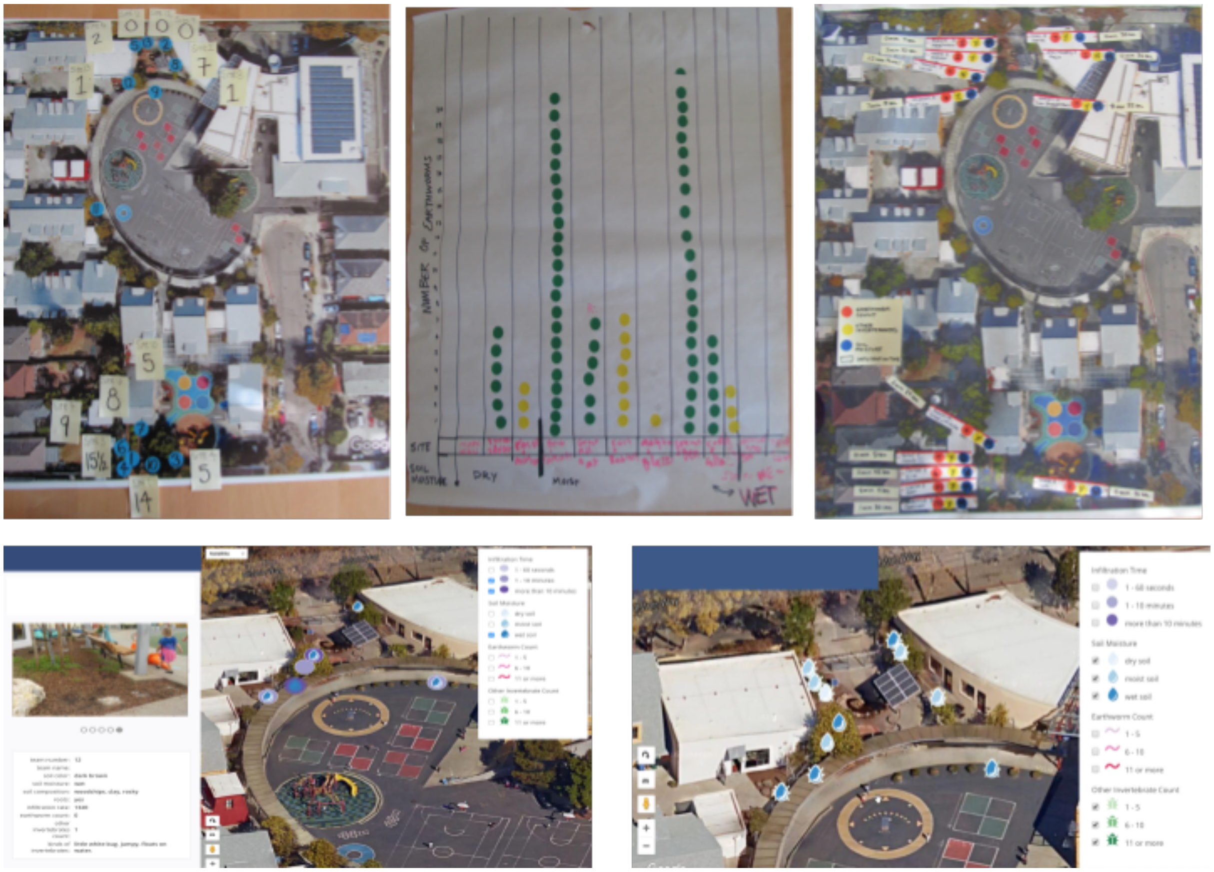


Figure 6. Examples of different student data forms, increasing in volume, scale, and interactivity of data. Shown here are (a) an annotated paper map with post its (showing pairs' earthworm counts), (b) bar charts of each site's earthworm counts and soil moisture, (c) sticker map (showing each sites earthworm counts, other invertebrate counts, and soil moisture), and (d, e) two Local Ground interactive map view (one with photos and text notes, the other with just symbolized variables) used during the Research Meeting.

Cycle II of ecologists' practices to support system level understanding.

Identifying parts of the system (lesson 13, 1 class session). Based on conversations about patterns and puzzles in the data as well as questions about the validity of certain samples, students had the opportunity to select a second site in the schoolyard to gather additional data to explore interrelationship among variables. They could either revisit their original site or select a new site to study. Students also were encouraged to capture additional details about aboveground activity, in the form of human movement and built structures. This added data was meant to address students' discussions conjecturing causal relationships between foot traffic, sunlight/ shade, children's favored play spots, garden activities, and recess games in relation to invertebrate species variation and total counts.

Transforming parts into variables (Lessons 14-15, 2 class sessions). Back outside, pairs worked together to collect another wave of site data. Based on relationships noted in the first round of data collection and visualization, many students also captured additional details about aboveground activity at their sites, such as human movement, nearby structures, and sunlight/ shade patterns (see Figure 7).

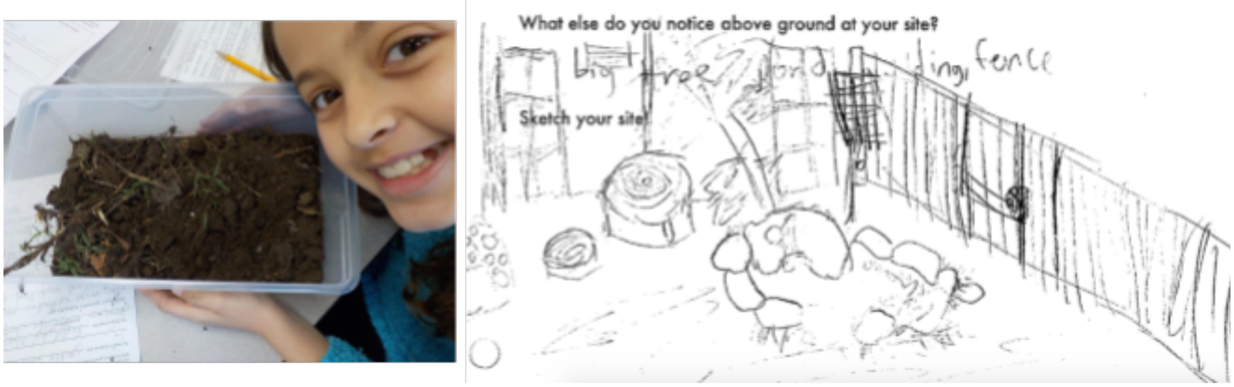


Figure 7. Student holding a soil sample from the school sports field and a student sketch of the pond area next to the 3rd grade classrooms.

Aggregating, visualizing and explaining (lessons 15-18, 4 class session). Back in the classroom, students added their second wave of data to *Local Ground*. After looking through the new wave of data, pairs worked to identify an interesting, surprising, or puzzling relationship in their data, focusing on relationships that including several variables or multiple sites. Following a Research Meeting format again, pairs took turns presenting their findings to the class in more extended formats. In Lessons 16, 17, and 18, pairs shared surprising, puzzling, or interesting patterns in their data and conjectured potential explanations and questions about these relationships. Discussion also centered on potential recommendations students could make to the principal and other school community members, in service of supporting more living organisms to thrive in the schoolyard system. After each pair presentation, there was extended time for peers to ask questions, offer connections with their own findings, and raise counter explanations. These peer presentations occurred over 2½ class sessions, with preparation for these presentations involving 1½ class sessions (see Figure 8).

Figure 8. Pairs exploring their second wave of data in *Local Ground*, and the presenting findings to their peers in a research meeting context.

Chapter 3
Methods

In this chapter, I describe the methods used to examine my research questions, including the research setting, participants, and data sources.

Research Setting and Participants

Classroom context. The study was conducted in an urban public elementary school (K-5) in the Western United States (40% free or reduced lunch, 16% designated English Language Learners, 12% African American, 6% Asian, 27% Hispanic or Latino, 45% White, 13% two or more races). This study was part of a larger three-year design study focusing on elementary children's engagement in participatory mapping, data science, and reasoning about socio-ecological systems (see Lanouette, Van Wart and Parikh, 2016 for earlier iteration findings working with a 4th grade class). Across both iterations, I served as the designer, teacher, and researcher. I worked closely with the elementary school science teacher, Ms. I, who had over ten years of science teaching experience and had participated in the prior iteration of the research project. In this most recent iteration, I also worked closely with one 5th grade homeroom teacher who had 15 years of teaching experience.

Study participants. The 5th grade class consisted of 27 students (14 males, 13 females), reflecting similar racial, ethnic, linguistic, and socio-economic demographics of the larger school community. All students participated in general activities, with 24 children consented to be part of the research study. In addition to studying whole class activity, I also focused on six focal students in more depth. The cooperating science teacher and 5th grade homeroom teacher recommended these six students, based on my request for focal students who attended school regularly, reflected the classes' varied demographics, ranged in scoring on state assessments, and would feel comfortable being interviewed several times.

Data Collection and Sources

I collected data at varying scales of activity - whole class, small group, and individual. Over the course of the 18 lessons, I gathered (a) **audio/ video data of each class session**, including audio/ video recording of all whole class activities inside and outside as well as focal dyads' activities when working at tables together. Video and screen recordings were also made of all students' use of the *Local Ground* maps, in both whole class and small group contexts. I collected all (b) **student and teaching artifacts**, including student's written and computer related work (using a screen capture software) and teacher/ student generated data forms. At four junctures, I (c) conducted four **semi-structured interviews** with the six focal students, enabling me to ask individual interpretation questions with the different forms, reasoning about site selection, and following up on discussion threads that emerged in earlier class sessions. Lastly, I conducted a (d) short **individual written assessment** with the participating class (n=26) and the other non-participating 5th grade class (n=25), which had received science instruction as usual.

Data sources. Below, I elaborate on the data source as they pertain to my larger research focus:

(a) Video and audio recordings. During each class session, I collected multiple video recordings, capturing interactions at the whole class, small group, and dyad level interactions. For whole class activity, I used two different cameras in each class session, including a classroom wide-angle camera capturing continuous whole class activity and a camera with a zoomed-in lens documenting discussions in the rug area. During small group table activities, I video recorded each of the three focal student pairs as well. Given the angle of these cameras, I captured the focal pairs interactions with the other focal pair at the table, recording not only the focal pairs interactions but also their conversations with the other pair at the table. During lessons that took the class outside the classroom, general activity was recorded using a wide-angle camera, focusing at times on the focal dyads' activities. I also wore a GoPro mobile camera during most class sessions, enabling me to capture my interactions with students and also add an additional perspective to the video record. Lastly, when *Local Ground* maps were being used by focal dyads' worked during pair work times and during whole class discussions, I captured computer screen, audio and video recordings of students' computer based activity using *SnagIt*, a screen recording software.

(b) Student and teaching artifacts. Across the 18 lessons, I collected all student and teaching artifacts. For each student, I collected all written work. In the planning stages, this included each student's data collection field notes and each student's site selection rationale sheet for each inquiry cycle. From the aggregation and discussion phases, student artifacts include students initial two site comparisons note sheets and their *Local Ground* data map exploration note sheets. I also collected student materials related to the research meeting, including each pairs' planning notes as well as individual student comments and questions in response to peer presentations. In addition to student artifacts, I also collected all teaching artifacts, which consisted of teacher chart notes recording student thinking and teacher-student co-assembled data forms, such as the sticker bar charts, the sticker data maps, and the invertebrate chart (see Appendix B for examples of student artifacts).

(c) Semi-structured interviews. At four points in the curriculum, I conducted semi-structured interviews with focal students individually. During these interviews, ranging from 20-40 minutes, I asked questions about the students experiences and decisions engaging in the three ecologists' practices up to that point, such as their expectation about what would be underfoot in the schoolyard, students' rationale for particular sites selected, their experiences collecting data in the schoolyard, and activities related to collective construction of varied data representations (bar chart, two way table, interactive digital maps). I also asked questions related to their interpretation with select representational forms, including the color photograph map (Interview #1), the sticker map showing select variables (Interview #2), the *Local Ground* interactive GIS map (Interview #3), and all representational forms (Interview #4). Lastly, I asked a repeated question about site selection and sampling practices involving zero or low counts in each interview. My aim with this question was to see how children's valuation of zero or low counts in sampling might shift overtime and the relation to their site selection rationales. In the last interview, I asked additional questions about students' reflections engaging in specific activities related to each practice and their recommendations for future iteration designs. (See Appendix A for full interview protocol for the four interviews, including repeating questions).

(d) Written assessment. After the last class session, I conducted a written assessment with the participating class (n = 25) as well as the non-participating class (n = 23) who had received science instruction as usual. I included questions related to interpreting fictitious garden data, sampling rationales, and considerations of bi-directional relationships in ecological systems. (See Appendix B for sample written assessment).

Together, these four data sources provide insights into students' sensemaking with varied data forms over time to construct, share, and contest different explanations of surrounding ecosystems underfoot, leveraging their familiarity with these local spaces and their participating in larger scientific practices to potentially reason about complex interrelationships. These data sources also provide multiple windows into learning and interaction, supporting triangulating multiple data sources (see Table 4).

Table 4
Data Sources Collected, across the 18 class sessions

	Practice Phase	Data Sources Collected
Cycle I	Identifying Parts of the System (Lessons 1-4)	Whole class video (including outside) (L1-L4) Dyad video: Site Planning Discussions Teaching Artifacts: Parts of System Brainstorming List, Parts of System (Living and Non Living), Site Selection Map #1 Student Artifacts: Site Planning Sheets, Site Planning Maps, Site Selection Sheet #1 Semi-Structured Interview #1 (post L4)
	Transforming Parts into Variables (Lessons 5 & 6)	Whole class video (including outside) (L5-6) Dyad video (L5-L6): Data Collection Activities Student Artifacts: Data Collection Field Notes #1
	Aggregation, Visualization and Explanation (Lessons 7-12)	Whole class video (L7-L12) Dyad video (L7, L10), including screen capture data of pairs editing and exploring data (L10) Teaching Artifacts: Collectively constructed bar charts, two way tables, sticker data maps, and interactive GIS data maps Student Artifacts: Patterns and Puzzle in our GIS map Worksheet #1 Semi-structured Interview #2 (post L9)
Cycle II	Identifying Parts of the System (Lessons 12 & 13)	Whole Class Video (L12-L13) Dyad video (L13), including screen capture data of pairs editing data exploring patterns and puzzles in the aggregate data (L15) and preparing their presentation for peers (L16) Student Artifacts: Site Selection Sheet #2
	Transforming Parts into Variables (Lessons 14 & 15)	Whole class video (outside and inside) Dyad video (outside and inside) Teaching Artifacts: Site Selection Map #2 Student Artifacts: Data Collection Field Notes #2
	Aggregation, Visualization and Explanation (Lessons 16-18)	Whole Class Video (L15-L18), including screen capture video of all map use Dyad Video (L15), including screen capture video of all pairs' digital map use Student Artifacts: Patterns and Puzzle in our GIS map worksheet #2, Presentation Planning Notes, Research Meeting Notes Teaching Artifacts: Presenting Pairs' Evidence and Claims Chart Semi-structured Interview #3 (post L17)
	Post Instruction	Student Artifacts: Written Assessment Semi-structured Interview #4

Chapter 4
Participatory GIS Maps in Elementary Students' Science Inquiry and Argumentation: Coordinating Everyday Knowledge of Place and Data in Collective Discussions

Chapter Abstract

Students bring a wealth of resources to science learning contexts, including knowledge of their everyday worlds and intuitions about creating and critiquing data. Yet within traditional approaches to K-12 science instruction, students typically are not given opportunities to draw upon this knowledge, potentially limiting student engagement in science and the conceptual depth with which children make sense of instruction in science. In this chapter, I examine the potential of an alternative to traditional science education practices in a fifth-grade classroom – a place-based 10-week science inquiry lesson sequence about life underfoot on students' own school yard. My focus is on three classroom discussions that occurred towards the end of the lesson sequence. In the discussions, students make use of Google-based GIS interactive mapping software, *Local Ground*, as they share their separate field inquiries and make and contest arguments to explain aggregated data about soil ecology. Analyses reveal that the GIS maps often afforded opportunities for students to coordinate their everyday schoolyard knowledge and their experiences collecting data at schoolyard field sites. This coordination supported productive integration of observations and measurements across students' different sites and across multiple observations at the same sites under shifting conditions. At the same time, despite the affordances of the GIS map software, analyses reveal particular occasions when the GIS map was used only indirectly. Instead, students made use of auxiliary forms such as gesture to support argumentations in which they drew on their field experiences and knowledge of everyday schoolyard knowledge. Gestural work occurred as students conjectured and contested causal explanations or when students wanted to provide an on-the-ground perspective of the schoolyard. Implications for the design of digital tool and science curriculum are discussed.

Introduction

Children often bring a wealth of resources to science learning contexts. One resource for understanding ecological systems is children's knowledge of their "everyday geographies" (Mitchell & Elwood, 2012). Children's everyday geographies include knowledge of places central to students' daily lives, including pets, local flora and fauna of their neighborhoods, as well as changing weather conditions, like temperature shifts in sunny and shaded areas, or what happens to the ground in their neighborhoods when it rains. This knowledge is multi-dimensional, rich with the smells, noises and routines of everyday life (Nespor, 1997). It encompasses numerous modalities for knowing such as physically moving through places (e.g., kinesthetic, embodied) and emotional connections to and about places (e.g., affective connections). Such knowledge also spans multiple time scales and places (e.g., Hart, 1979; Lim & Barton, 2010). For example, this knowledge unfolds across minutes, days, weeks and years and takes place in a wide range of contexts integral to children's lives, such as home, school, and surrounding neighborhood cultural resources.

Current approaches to K-12 science often make it challenging for children to leverage this varied knowledge about the living, built, and social worlds central to their everyday lives. Science instruction is often designed to be universal, both nowhere and everywhere, with minimal curricular connections to local contexts, experience, and questions central to children’s daily lives (Gruenewald, 2003b, 2003a). At the same time, science learning is often bounded by the classroom walls, in what Lenader et al. (2010) call the “classroom as container”, constraining both physical mobility and inquiry outward into local contexts and related systems. In ecological sciences, this traditional approach most often manifests in students either studying computer simulations of hypothetical systems or working with pre-collected data about far away contexts. While such approaches may be useful for elevating associations among variables and potential mechanisms for interaction, this approach doesn’t leverage children’s varied and often extensive knowledge of their “everyday geographies” (Elwood & Mitchell, 2013). As a result, many students may not engage and integrate their existing knowledge with science instruction, limiting conceptual and critical depth of their science reasoning and argumentation.

Promising new approaches in learning sciences and science education research have sought to address these challenges through place-based science inquiry. This pedagogical approach centers the study of science around students’ local contexts, with students engaging in data collection out in the field and argumentation. Within this approach, there is a deliberate aim to localize and contextualize science instruction, as a means to support children’s conceptual and critical reasoning. There is also an aim to leverage children’s “everyday geographies” as integral funds of knowledge (Barton & Tan, 2009; González, Moll, & Amanti, 2007) in reasoning about larger processes and systems. As such, this approach can result in children’s ability to work with and make sense of data and to reason about larger systems and processes, drawing on their everyday experiences in meaningful ways.

Yet there are challenges with this approach as well. First, students may have difficulty moving between their everyday experiences, their field observations, and the aggregated data they generate. Such difficulty may become evident in classroom discussions in which students put forth evidence and claims using data. Prior research has documented how students can get rooted in their local, first person experiences, ignoring disconfirming evidence or patterns in aggregate spatial data (Rubel et al., 2016; Wilkerson & Laina, 2018) As a result, it can be challenging for students and teachers alike to meaningfully navigate between qualitative, often direct first person experiences and more abstracted, aggregated quantitative ways of knowing (e.g., Enyedy & Mukhopadhyay, 2007).

Second, students may well have difficulty coordinating and integrating observations and measurements across space (different field sites) and time (repeated measurements at the same site that occur at different time points). For example, consider the challenge when everyday experiences and data often occur on varying scales in space, from small tucked away corners of the schoolyard to distributions of data points across city blocks and even neighborhoods. Additionally, children’s everyday knowledge and their data collection experiences span multiple time frames, from minutes and days to weeks and years. As such, it can be challenging for children to both shift between individual experience and aggregate data and to coordinate different scales of activity unfolding across different temporal trajectories in collective discussions. Yet such coordination is important is science sense making, especially in ecology, which focuses on the relationships between organisms and the environment across space and time (Forsythe, 2018).

Recent research involving Participatory Geographic Information System (GIS) mapping tools has pointed to the potential of these tools to support these challenges in argumentation, as students coordinate and integrate experiences that occur in different locations and points in time. These technologies support collecting, transforming, and visualizing data, in a range of data formats (quantitative and/or qualitative) to explore underlying processes at multiple spatial and temporal scales. GIS mapping tools have shown potential in supporting youth integrating their first person experiences in everyday spaces as they reason with complex data about larger socio-political systems and processes (e.g., Kornbluh et al., 2015; Rubel, Hall-Wieckert, & Lim, 2017; Taylor & Hall, 2013). Recent research has documented powerful ways in which digital mapping tools can support both critical conceptual learning and new forms of participation as well (Headrick Taylor, 2017).

Yet to date, existing research involving GIS maps has tended to involve older students and in non-science disciplines. Additionally, research approaches to studying these tools have focused on individual or small groups of students' uses of these tools or simply the static map representational forms separate from their argumentative uses. As a result, there remains much to learn about how younger students might use these increasingly ubiquitous digital mapping technologies and the potential role of these tools in collective science disciplinary pursuits.

In this study, I examine elementary students' use of digital GIS maps, with a focus on how students navigate the challenges of moving between individual, first hand experiences and aggregated data to reason about complex processes. To support elementary students learning about ecological systems and leveraging their "everyday geographies" as integral to their reasoning about ecological systems, I designed a ten-week instructional sequence centered around the school's outside yard, an environment that students knew from different perspectives and through the use of different modalities (e.g., kinesthetic, affective). Over 18 class sessions, students were supported in two cycles of data collection, aggregation and visualization. Working in pairs, students selected and collected data at two sites of their choosing, compiling these data with their classmates' data to explore relationships across schoolyard sites and a range of variables. Mapping was a core representational activity throughout both cycles, with students using *Local Ground*, an interactive web-based mapping platform (Van Wart & Parikh, 2013), from early discussions marking potential schoolyard sampling sites to collective class discussions where students conjectured and contested relationships in the aggregated data.

To study the potential of place-based science inquiry and children's use of digital maps in children's collective classroom discussions, I draw on Saxe's approach for understanding cognition as process as students draw upon representational forms to serve functions in argumentation and communication. In the framework, representational forms, like the GIS map or pointing and mimetic gestures, come to serve specific functions as students make reference to data gathered in their schoolyard field sites in conjunctions with their everyday schoolyard knowledge (Saxe, 2012). In this chapter, I examine three classes at the end of the curriculum where children led discussions using the interactive GIS maps. I ask the following questions:

> (1) As students' conjecture and contest evidence and claims, do they make use of the GIS maps to support their argumentation? Do they draw on their everyday schoolyard knowledge and data collection experiences? Does the map serve useful functions in supporting coordination and integration of their everyday schoolyard knowledge, their data collection experiences and their reasoning with aggregated cross-site data?
>
> (2) How do students use the map and other representational forms in coordinating their everyday schoolyard knowledge and data collection experiences? Are there occasions in which the GIS map is put aside in supporting argumentation? If so, do students' draw upon other representational forms to serve similar functions?

The remainder of the chapter is partitioned into four sections: In the first, I describe the theoretical and methodological approach I take to studying students' use of the GIS maps in science discussions. In the second, I present the *Local Ground* mapping tool and the way it was used within whole class discussions with a focus on student presentations. In the third, I move to my methods for analysis in conjunction with a presentation of my findings. In the fourth, I conclude with a discussion of implications for both digital GIS mapping tools and science curricular design.

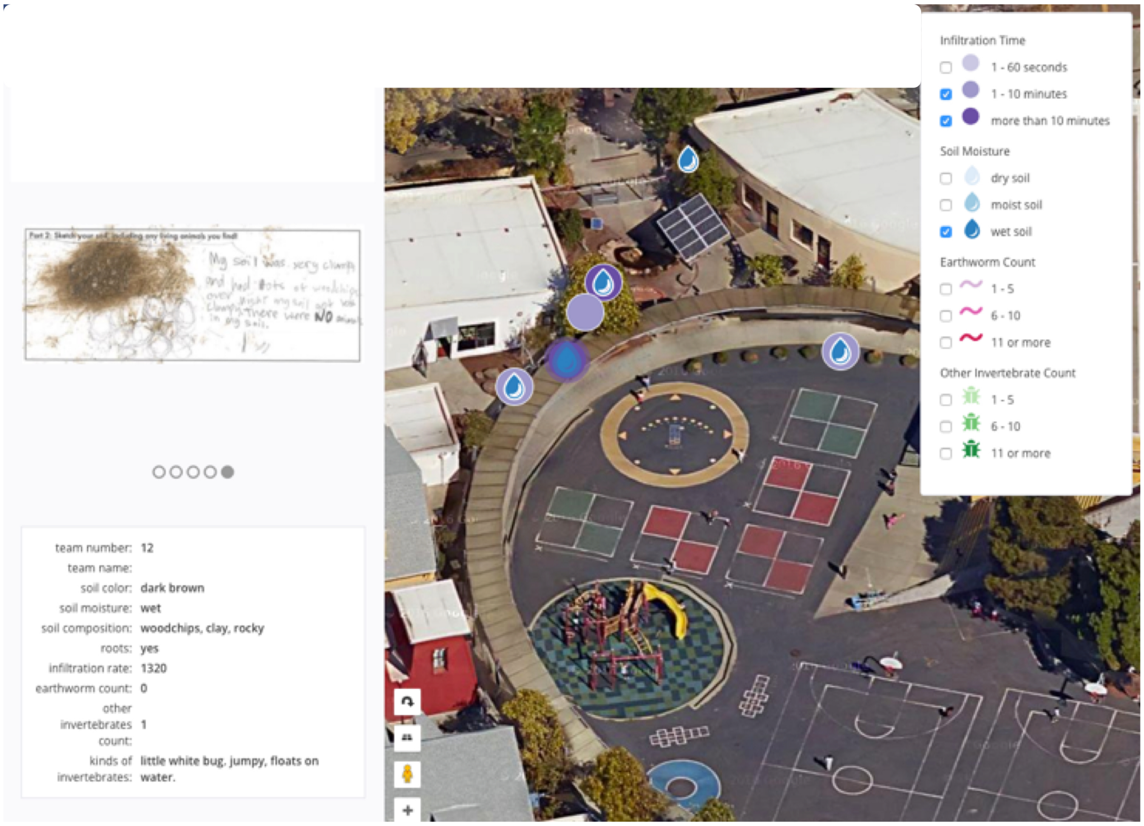
Theoretical and Methodological Approach to Studying Digital Tools in Classroom Activity

I draw on Saxe's (2012) form/ function framework to study students' use of the *Local Ground* maps in whole class discussion. In this framework, there is a focus on how participants in collective practices, like students' presentations in local ground classrooms, use cultural forms to serve specific functions as participants conceptualize and accomplish emergent problems. Saxe (2012) defines collective practices as "recurring structures of social activity that are constituted as people construct, communicate about and accomplish recurrent problems over time" (Saxe, 2012, pg. 22). This theoretical and methodological approach illuminates the ways the map and other representational forms supported students in drawing on their everyday schoolyard knowledge and their data collection experiences at local schoolyard sites as they reason with their aggregated data.

Digital GIS Mapping Tool Design

***Local Ground* core principles and functionalities.** *Local Ground* is a participatory GIS mapping tool (Van Wart & Parikh, 2013), that has been developed through multiple iterations, with the most recent iteration being the focus of my analysis. Three key design principles guided the iterative development of the *Local Ground* design, including supporting (a) multiple data types, such as drawings, photos, audio recordings, and text notes in conjunction with quantitative data forms, (b) engagement in end-to-end mapping and data processes including designing protocols, analyzing data, and representing findings in varied formats; and (c) collaboration, where youth can collectively author the same map or create multiple variations drawing from the same collective data set. The purpose of the principles were to support youth to produce, analyze, and represent local data about their daily lives as well as participate in discussions and analyses that are heavily mediated by data (and/or representations of those data). Unlike traditional GIS mapping technologies designed for professional activity with existing data sources, participatory GIS mapping tools like *Local Ground* support youth creating maps using their own data to support inquiry into local questions and process relevant to younger peoples' lives (Lanouette et al., 2016; Van Wart, Lanouette, & Parikh, 2016)

Representational forms in *Local Ground*. Several different representational forms constitute the *Local Ground* screen views, including (a) a color Google map base, (b) varying iconic forms presenting variables and data values (e.g., students' numerical data including infiltration times, soil moisture, earthworm counts, other invertebrate counts), and (c) the qualitative panel form that includes students' photographs, sketches, and text notes. All three representational forms are interactive, readily accessible and manipulable as children construct maps with their data. The three forms are shown in Figure 9, including (a) the color Google map base form, (b) iconic data form (on the right side of the figure), and (c) the qualitative data forms on the left (sketches, photos, notes).



Infiltration Time
☐ ● 1 - 60 seconds
☑ ● 1 - 10 minutes
☑ ● more than 10 minutes
Soil Moisture
☐ dry soil
☐ moist soil
☑ wet soil
Earthworm Count
☐ 1 - 5
☐ 6 - 10
☐ 11 or more
Other Invertebrate Count
☐ 1 - 5
☐ 6 - 10
☐ 11 or more

Part 2: Sketch your soil, including any living animals you find!

team number: 12
team name:
soil color: dark brown
soil moisture: wet
soil composition: woodchips, clay, rocky
roots: yes
infiltration rate: 1320
earthworm count: 0
other invertebrates count: 1
kinds of invertebrates: little white bug, jumpy, floats on water.

Figure 9. Local Ground interface's many forms, including the (a) underlying color Google map base form, (b) iconic data form (on the right side), and (c) the qualitative data form (on the left) accessed by clicking on individual sites, and the color photograph map form underneath.

Form a: "Zoomable" google map of the schoolyard. This form uses a Google maps base layer interface. Students can zoom in or zoom out using the + and - symbols on the bottom level of the screen or pan to different locations by dragging the screen with the mouse. Although the background of the map is changeable, a color photograph base was used throughout the curriculum.

Form b: Iconic forms representing variables and data values*.* This form includes a panel of iconic representations of variables (and values of those variables) positioned in the top right-hand corner of all maps. These variables were pre-selected by myself and the lead *Local Ground* designer, Sarah Van Wart, to support students' reasoning about different organisms (e.g., earthworms and other invertebrates) in relation to important soil characteristics (e.g., soil compaction, soil moisture). By clicking with the mouse on the empty squares next to the icon, students can visualize select data. This interactivity supported exploring the data values in varying configurations. For example, students could examine just one site and one variable (e.g., earthworms counts at one site), one variable across all sites (e.g., earthworm distribution across the whole schoolyard) or several variables within smaller sub areas (e.g., earthworms, invertebrate counts, and soil moisture in just the school garden and the pond areas).

Alternatively, students could explore just slices of data values. For example, as shown in Figure 9, students have selected two variables (infiltration time and soil moisture) and the according subfields of "1-10 minutes", "more than 10 minutes" and "wet soil".

Form c: Qualitative forms representing sketches, photos, and text notes. This form can only be accessed by clicking on a specific pair's site. Once clicked, a panel on the left side of the map appears (see Figure 9c for one pair's soil sample sketches and written notes). In this panel are students' scientific sketches, photographs, and original notes. It also includes additional data not included in the iconic data form such as soil color, soil composition, prevalence of roots, raw infiltration time in seconds, and text descriptions of the non-earthworm invertebrates that were in their field samples. Students could scroll horizontally through the different sketches and photographs or scroll vertically to view the full original text notes.

Collective Practice of Research Meetings

In this analysis, I focus on students' activity within a recurring collective practice (Saxe, 2012) I call Research Meetings. Building on Lehrer, Schauble, and Lucas (2008), Manz (2016) and Forsythe's (2018) activity structure, these whole class meetings were designed to support students conjecturing and contesting evidence and claims using the classes' aggregated data, with an emphasis on moving towards explanations. Class discussions were organized around the map as an integral form, within which every pairs' two sites and related data were represented along with their classmates' data. Roles were not static, with pairs presenting initial evidence and conjecturing claims about relationships in the data and then classmates able to direct control of the map or invited up to contribute insights and questions. Throughout the discussions, each student had a clipboard to record questions, comments, or connections with ideas raised by the presenting pair. This was done to ensure that student ideas could be recorded and shared regardless of if the student spoke in whole class activity. The author stood or sat at the front of the room, writing down pairs' evidence and claims on large chart paper and the science classroom teacher sat amongst the children, often in the back of the classroom (see Figure 10 for photograph of collective research meeting discussion set up).

Figure 10. Research meeting classroom set up. This photo shows the typical arrangement for research meetings, with (a) one pair controlling the interactive GIS map and discussing conjectures using the aggregated data, (b) Kathryn recording the main claims and evidence discussed by each pair on large chart paper, and (c) classmates sitting on the rug recording notes and questions on their note sheets. Note students with clipboards, with one child on the left writing as the pair presented.

Methods

Selection of focal lessons. To examine how students used the map as they conjectured and contested evidence and claims about ecological relationships and possible mechanisms, I selected three class sessions at the end of the 18-lesson curriculum. In these classes following a research meeting format, student pairs had the opportunity to share interesting, puzzling, or surprising patterns using the class level data. As described in the introduction, I selected these three class sessions because students were encouraged to use their aggregated data within the interactive GIS maps as they engaged in often extended discussion about potential ecological relationships and explanations with their classmates.

Data sources. Data sources included (a) two video cameras recording whole class discussion from different angles, including a back of the classroom angle capturing presenting pairs' use of the map and a front facing, wide angle capturing the pair and classmates activity, (b) screen capture video data from the pairs' laptop computer using SnagIt! software and (c) audio recordings.

Phases of analysis. Data analysis unfolded across two phases. First, I asked whether, across all of the 13 presentations, the map was used in the collective discussions and if and the extent to which children drew on their everyday schoolyard knowledge and their data collection experiences. Second, I provided a more nuanced analysis of four selected cases; the cases were chosen to illuminate whether as well as the ways in which students used the map as an arena to coordinate their everyday schoolyard knowledge and their data collection experiences in argumentation. Further, in these cases, I also consider occasions in which the map was not used and whether there were alternative representational forms used by students to coordinate their everyday schoolyard knowledge and their data collection experiences in argumentation.

Phase 1 of analysis: Students' use of maps, everyday schoolyard knowledge and data collection experiences in research meetings. In this first phase, a research assistant and I reviewed the video record for the three focal class sessions, focusing on students' use of the maps, their everyday schoolyard knowledge and their data collection experiences.

Video logs. Initially, we began by creating video logs of activity for the three class sessions, focusing on all 11 pairs' presentations. We bounded these presentations from the start of the pair's opening conjectures to the end of the ensuing discussions. Within each pair's presentation, we noted the ecological ideas or explanations that students raised (e.g., different animals needs are met in different locations, earthworms change the soil through their tunneling). We also noted the characteristics of data students drew on in their opening conjecturing, including the number of variables, the types of variables, the volume of data used (e.g., number of sites) and the format of the data (iconic or qualitative). We also noted what scale of the map was used (e.g., showing the whole schoolyard or just a select area). (See Appendix C for the pair presentation video log summaries).

Students' map use. Using video coding software (*Angles*), I recorded durations of time when the map was use within each student pairs' presentations. I defined map use as any physical gesture toward or manipulation of the interface, as well as verbal reference to the map interface and embedded data. Once all durations of map use were identified, I returned to these instances to examine which forms of the map were being used (see coding table in Table 5). Building on earlier iteration findings and coding schema developed to describe students' map use (Lanouette, Van Wart & Parikh, 2016), I elaborated on these codes with greater specificity and attention to smaller forms within the map (e.g., iconic data and qualitative data). This approach to coding enabled me to document durations of map use in collective discussions as well as different uses of the map forms.

Table 5

Varied Forms, including Code, Sub-codes and Definitions

Code	***Sub-codes***	***Definition***
Map		Any instance clicking, gesturing toward, and/ or talking about the map, referring to the spatial layout or the details visible in the color photograph such as built structures and plants (e.g., pointing to a particular location, verbally stating "Look at the garden! You can see trees are everywhere!"
Data	Iconic (First layer)	Any instance clicking, gesturing toward, and/ or talking about the subfields in iconic data(e.g., clicking on 1-5 earthworm category box, gesturing to iconic variables depicted on the right side pane of the map)
	Qualitative (Second Layer)	Any instance clicking, gesturing toward, and/ or talking about photographs, sketches, or text notations) (e.g., talking and gesturing with mouse to describing text notes about root structures)
Hybrid		Collapsing map and data aspects inseparably together (e.g., describing earthworm counts in the garden area, using sweeping gesture across both the earthworm data and the pond area)

Everyday schoolyard experiences and data collection experiences. Using the same video coding software (*Angles*), I then marked all instances within each pairs' presentation of students reference to their (a) everyday schoolyard experiences and (b) data collection experiences. Table 6 contains definitions for these codes. I included both verbal and gestural references to these two experiences. For example, for everyday schoolyard experiences, I included verbal statements about the schoolyard (e.g., "That area is often full of kids talking") as well as gestures (e.g. gesturing over section of the map to show where children play at recess or where the flood waters gather during the winter rainy season). Similarly for data collection experiences, I included all verbal discussions explaining sampling experiences (e.g., "we worked around the concrete to get a good soil sample there") as well as gestures (e.g., moving hands apart to show the narrow confines of one pairs' sampling site).

Table 6

Everyday Schoolyard and Data Collection Experience Codes and Definitions

Code	***Definition***
Everyday Schoolyard Experiences	Any verbal or gestural reference to the schoolyard, including knowledge about environmental conditions, human activity, and emotional experience/ feelings within schoolyard space.
Data Collection Experiences	Any verbal or gestural reference to data collection experiences, including sampling activities out in the schoolyard and representational activities transforming the data after collection

This approach to video coding enabled visualizing not only the frequency of children's uses of these different ways of knowing of the schoolyard (e.g., everyday schoolyard and data collection experiences) but also, how students were moving between these two different kinds of experiences across presentations as they shared and contested evidence and claims related to ecological systems. For example, in Figure 11, one pair's presentation (pair 4) is shown in the video coding window. The long purple rectangle depicts the total duration of the pairs' presentation. Within the presentation, green dashes show instances of students drawing on their everyday schoolyard knowledge and blue dashes show instances of students drawing on their data collection experiences. It is possible to see not only frequencies but also how the different experiences were drawn on – or not drawn on – throughout the presentations.

Figure 11. Video coding window for pair 4's presentation, showing instances of everyday schoolyard experiences (green dashes) and data collections experiences (blue dashes).

Phase 2 of analysis: Selecting vignettes from larger data corpus focusing on coordination. In this phase, I focused on *how* students were using the map as they coordinated their everyday schoolyard experiences, their data collection and transformation experiences, and their reasoning with the cross-site aggregated data. I also consider occasions in which students did not use the map but nonetheless made efforts to construct similar coordinations. To do this work, I revisited each pair's presentation. I examined durations of time where there were instances of coordination (see Figure 12a). Within these durations involving coordination, I examined how the *Local Ground* maps were being used and the ecological ideas being discussed. I also revisited periods where coordination appeared absent (no blue or green dashes), examining how the maps were being used within these durations of activity (see Figure 12b).

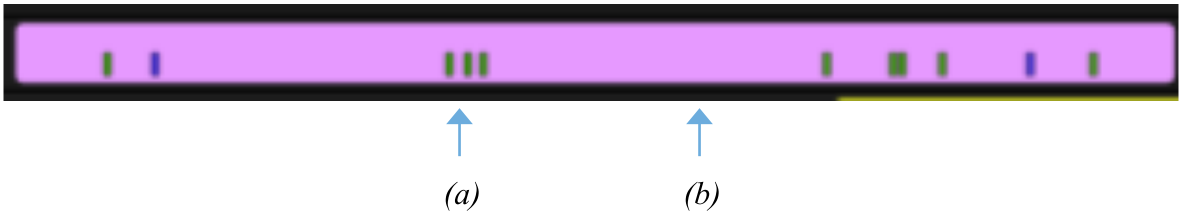


Figure 12 a,b. Video coding window for pair 4, showing areas of (a) coordination and (b) no coordination that were examined in depth.

I selected four descriptive cases from a larger corpus of coordination durations involving and not involving the map, with attention to students' coordinating their individual and aggregate experiences across space and time. I selected these cases to illuminate how different coordinations supported insights into ecological processes and systems.

Results

I present my results in two sections. In the first section, I document across all 11 presentations the extent to which students used the map. I also document the extent to which students made reference to their everyday knowledge of the local school geography and their data collection experiences both using and not using the map. In the second section, through selected cases, I show *how* students coordinated their everyday schoolyard and data collection experiences as the conjectured and contested arguments related to claims about their own and classmates' data. The four cases I analyze illuminate the dynamics of students' coordination when students used the map as well as occasions in which students used other representational forms (e.g., gesture). In the first two cases, my focus is on students' map use and in the second two cases, I examine students' coordination when they chose not to use the map. Across all four cases, I highlight how students' coordination, using varied forms, supports reasoning about ecological systems and rich coordination of multiple experiences and data across time and space.

Section I: Students' Map Use, Everyday Schoolyard Knowledge and Data Collection Experiences Summary

Students' map use. Across the 11 presentations, students used the interactive GIS maps often as they conjectured and contested potential relationships and explanations about the schoolyard socio-ecological system. Map use included physical manipulations of the interactive GIS map interface, such as selecting specific variables in the interactive panel, pulling up varied data formats and shifting the scale and location of the underlying color photograph map. Map use also included verbal references to the map (e.g., "As you can see, the area has lots of trees!") and gestures towards and across the map surface (e.g., pointing to specific locations or running fingers across surface to show children's daily movement through the schoolyard).

Students' use of map forms to serve specific functions. Through a closer analysis of the students' map use, students made use of specific map forms in inventive and varied ways, to serve different functions in collective conversations (see Table 7). Students' used the map forms for several different functions, including clarifying spatial locations or showing proximity between locations, much as one uses a traditional map. Students also used the map form to point out or gather new information from the color photograph, such as pointing out building locations or searching the photograph to see if there is shade in a specific location. The data form had two sub forms – iconic and qualitative. Students used the iconic data forms to explore, share, and contest spatial distributions among select variables. This included just one variable and one subfield within that at a site (e.g. only 1-5 earthworms) up to several variables at all 24 sites (e.g. invertebrate counts and soil percolation times, across the entire schoolyard). There also were instances where the forms were blended together inseparably, coded as hybrid forms. In Table 7, I show the different map forms and useful functions served in students' discussions.

Table 7

Shifting Map Forms to Serve Shifting Functions

Forms	***Sub forms***	***Functions***
Map		* Clarify or contest spatial location (e.g., pointing to a particular location) * Show proximity/ spatial positioning of two locations to one another * Focus attention on particular location in schoolyard (e.g., field sites, pond area) * Serve as backdrop to gestures grounding varied schoolyard knowledge onto the map surface, such as hand sweeps across area prone to flooding, cupped hand movements showing shady locations and running motions with fingers across the blacktop area to show children's daily foot traffic patterns * Clarify or contest details about specific visible attributes in locations, such as tree canopy fullness in the blacktop area or the location of playground equipment * Gather new information about the schoolyard and students sites, such as searching the color map for additional details visible in the color photograph (e.g., built structures and plants locations)
Data	Iconic (First layer)	*Explore and share spatial distribution of specific variables (e.g., examining all earthworm counts across the entire schoolyard) or multi-variate relationships (e.g., examining relationship between invertebrate counts and soil compaction rates) at one, site, a small subset of sites or across all sites *Clarify or contest conjectured relationships among variables (e.g., such as earthworm count and soil moisture relationships) *Clarify or contest timing of data collection at specific sites (e.g., by examining soil moisture at site in relation to recent rainstorm)
	Qualitative (Second Layer)	* Explore, clarify or contest evidence or claims, by retuning to the original data collection notes in their entirety (e.g., using the text notes to see (a) actual species names recorded (not just total invertebrate counts shown in iconic data panel), (b) precise percolation time measurements (not just the range offered by iconic data panel), (c) additional text notes about the soil composition like texture and component parts (not just moisture and compaction iconic data) or (d) scientific sketches of the sampling site (not just icons and the color photo map)
Hybrid		*Clarify or contest conjectured relationships, collapsing map and data aspects inseparably together (e.g., using iconic data to show potential co-variate relationships (e.g., such as earthworm count and soil moisture relationships) and using color photograph to conjecture how context specific details such as building location and children's daily foot traffic might be influencing select variable results at specific sites

Students' everyday schoolyard knowledge and data collection experiences in presentations summary. Across the 11 pairs presentations, students drew on the everyday schoolyard knowledge and their data collection experiences numerous times. As evidenced in Table 8, there was variation in how often students drew on these different experiences. In some presentations, students frequently drew on their everyday schoolyard knowledge (maximum 11 times) and data collection experiences (maximum 14 times), whereas other pairs' presentations didn't involve this knowledge and experiences at all (minimum 0). The mean across presentations was 3.4 for everyday schoolyard knowledge and 5.3 for data collection experiences.

Table 8

Descriptive Statistics for Students' Uses of Everyday Schoolyard Experiences and Data Collection Experiences During Pairs' Presentations

Student Pair	Everyday Schoolyard Knowledge	Data Collection Experiences
1	1	0
2	7	1
3	9	6
4	11	2
5	3	13
6	1	14
7	0	1
8	1	5
9	1	4
10	3	10
11	0	1
Sum	37	57
Max	11	14
Min	0	0
Mean	3.4	5.2
Median	1	4
Mode	1	1

Everyday schoolyard knowledge. Across the 11 presentations, students drew on their everyday knowledge 57 times, expressed in verbal utterances and gestures. Children's everyday schoolyard knowledge included detailed knowledge about the physical environment and related processes, such as sunlight and shade patterns, areas prone to flooding and plant and animal distributions. Such knowledge spanned across the day, seasons, and even years. For example, children described the shade patterns cast by buildings each afternoon (e.g., "You are likely to find spiders along the shady part of the building"), discussed specific locales that tended to flood during the annual rainy season (e.g., "Each winter, it always floods in that spot") and noted animal distributions (e.g., "I used to pet the bees over there by those flowers in third grade.").

Students' everyday schoolyard knowledge also included detailed knowledge of human activity with the schoolyard space, such as daily patterns of children and adults' movement and noise levels related to varied activities. For example, students would often trace a wide arc across the map to show how kids moved across the schoolyard spaces. They also drew on detailed knowledge of specific locations, to describe human activity at smaller scales of activity (e.g., "No one goes over there much, not even the Kindergarteners", "The principal eats lunch there every day."). Such findings are consistent with existing research on children's multi-modal and varied knowledge of their "everyday geographies", rich with the smells, noises and routines of everyday life across time and space (Hart, 1979; Mitchell & Elwood, 2012; Nespor, 1997; Tuan, 1977).

Data collection and transformation experiences. Across the 11 presentations, students drew on their data collection and transformation experiences 57 times, expressed in verbal utterances and gesture. Children drew on their experiences collecting data, including first-person experiences at pairs' own site gathering data This included specific experiences digging up soil samples, counting and identifying invertebrate species, and determining soil percolation rates at pairs' own sites. Children also drew on more general knowledge about data collection tools and processes for using these tools. This included understandings such as the steps entailed to gather an accurate soil compaction reading.

Children also drew upon their experiences transforming the data, as they moved from field note sheets full of sketches, text notes, and tally marks to symbolized and digital forms where several counts were collapsed into categorical ranges. For example, students collected soil samples at their sites, counting and tallying earthworms. They then added their numerical counts into the interactive GIS map interface, with counts split into three categories: 1-5 earthworms, 6-10 earthworms, and 11+ earthworms. When students drew on their data collection experiences, they often referenced this transformation process (e.g., Elizabeth, " I know it says 1-5 but we had five earthworms at our site").

Section II: Students' Coordination with and without the Map

In this section, I focus on *how* students used the Local Ground maps and other forms to coordinate their everyday schoolyard knowledge and their data collection experiences as they conjectured and contested evidence and claims. I analyze four selected student presentations and ensuing discussions to illustrate the variety of ways students coordinated their experiences using multiple forms. In these cases, students used particular forms embedded in the GIS map (e.g., map form, iconic data form, qualitative data form), often drawing upon their knowledge of everyday geography and data collection experiences to support their argumentation. In addition, I analyze occasions in which the GIS map was backgrounded by students, where students used auxiliary representational forms to serve argumentative functions. Across these four cases, I elevate the important ecological ideas or processes that emerged in discussion as students coordinated their experiences and data using shifting map forms.

Students' Use of the Map to Coordinate Experiences: Two Cases

In the following two cases, I show how students drew on different map forms as they coordinated their everyday schoolyard knowledge, data collection experiences, and the class's aggregated cross-site data. I show how students' shifting use of varied map forms and the coordination of data and experience supported generative discussions about ecological systems and processes, as well as varied entry points into collective science argumentation.

Case A: Lena and Max's earthworm and shade conjecture (class 16, pair 3, 1:10:15 -

1:18:55). Lena and Max put forth a complex conjecture: high earthworm counts occur in locations with moist soil, roots *and* shade. As students consider and contest the pair's opening claim, students draw on the class's cross-site data, their everyday schoolyard knowledge, and their data collection experiences to reason about earthworm needs in relation to the schoolyard environment. As they do so, they consider multiple variables at numerous sites. Throughout, different map forms are used to serve different functions in conversation, often supporting the coordination of students' experiences and multiple types of data.

In this case, I examine Lena and Max's presentation and the ensuing discussions I first consider the foregrounding discussions that occurred in earlier presentations and class sessions to establish common agreements that were emerging. Then, I analyze three segments of the pair's presentation, consisting of Lena and Max's opening conjecture followed by two counter claims made by other students in the class. In the first counter claim, one student, Marcel, contests Lena and Max's claim that it is shady at their second sampling site. Marcel argues that the pair's sampling site isn't shady, drawing on his everyday schoolyard knowledge of a tree at the current year. In the second counter claim, Ellis contests Lena's and Max's claim, using his own site data and experiences collecting data. He argues he and his partner worked in similar conditions (e.g., moist soil, shade, roots) but they only found one earthworm, disconfirming Lena and Max's opening conjecture. Across these different segments of the presentation, I analyze how students use the map's many forms to coordinate their different experiences as they reason with the aggregated cross-site data (see Table X).

Context for Lena and Max's opening conjecture. Prior to Lena and Max's presentation, students in class discussions had drawn a strong relationship in the aggregated cross-site data between sites with high earthworm counts and moist soil. This relationship had emerged in both the first and second rounds of data collection and aggregation. As a result, it was a relatively well agreed upon relationship with the map used to show these clear patterns. Yet immediately before Lena and Max presented, another pair, Mia and Taye (pair 2), argued that maybe earthworms didn't need moist soil, showing sites with moist soil and relatively low earthworm counts using the iconic data and map forms. When Lena and Max presented, they offered a complex conjecture: high earthworm counts occur in locations with moist soil, roots *and* shade, evoking a new variable, shade (see Table 9). This new variable had yet to be considered by the class and is itself notorious for being challenging for students to visualize and integrate into reasoning about ecological systems (Manz, 2015).

Table 9

Summary of Lena and Max's Presentation Segments.

This table shows students' conjectures and counter claims as well as shifting map forms and experiences drawn upon. [Class 16, Pair 3, 1:10:15 - 1:18:55]

Presentation Segment	*Students' Claims*	*Drawing on*	*Forms Used*
Opening conjecture made by Lena and Max [1:10:15 - 1:16:00]	Earthworms thrive when there is moist soil, roots and shade	Everyday schoolyard knowledge (Lena)	Map form Iconic data form Gesture
First counter claim made by Marcel [1:16:00 - 1:17:22]	Lena and Max's sampling site is not actually shady this time of year	Everyday schoolyard knowledge (Marcel, Lena) Data collection experience (Lena)	Map form Gestures
Second counter claim made by Ellis [1:17:23 - 1:18:55]	Our site had similar conditions but we only found one earthworm	Data collection experiences (Ellis, Lena, Max)	map form Iconic data form

Lena and Max's opening conjecture: Earthworms need moist soil, roots, and shade. In their opening conjecture, Lena and Max shared the earthworm data across the entire schoolyard. With their initial data map view set to the garden and earthworm data selected for the class's 24 schoolyard sites, Lena began presenting (see Figure 13):

Lena and Max’s Opening Conjecture

“So I am going to disagree with Mia, sorry. I think it [high earthworm counts at sites] actually has a LOT to do with shade and stuff because worms need lots of moist soil and … shade too! See at the garden (*pointing to the garden area*, *indicated by the red arrow in Figure a*), there is lots of shade because there are lots of trees.”

Figure a. Map of School Garden

“Now go to the pond (talking to Max, *who adjusts the map to show what is presented in Figure b*). And so at the pond, as you can see there is a lot more sunlight (*pointing to the sunny pond areas in a sweeping motion, indicated by the red arrow in Figure b*) and there is not a single eleven or more worms (*pointing to iconic data variable forms on right side of map, indicated by the blue arrow in Figure b*) because there is soooo much sunlight and the soil isn’t really moist, most of it is dry so I think shade AND soil moisture have a lot, a loooooot to do with worms.”

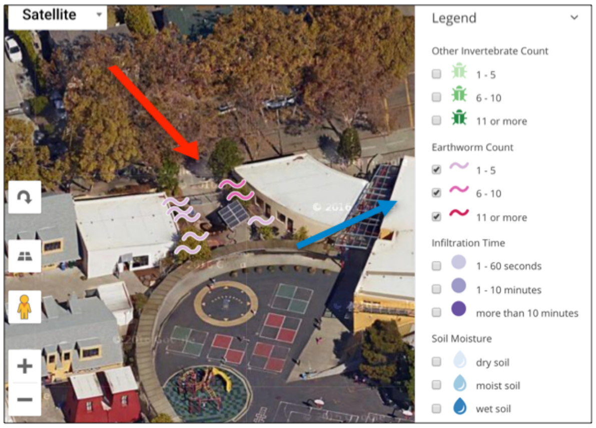


Figure b. Map of Pond

Lena and Max then change the map location again, to show earthworm counts at their second sampling site near the playing fields (Figure c).

“All the worms here has to do with shade, ‘cause we have shade from our decomposing lavender bush and the cherry tree (pointing to her site on Figure c). So we have shade, roots, moisture, and as you see, lots of worms!”

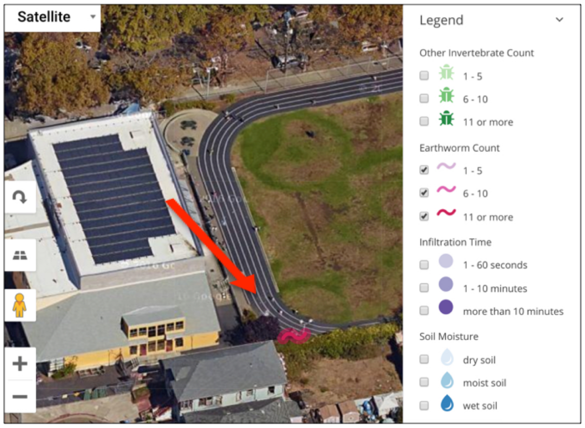


Figure c. Map of Sports Fields

Figure 13 (a-c). Screen captures of the shifting iconic data forms and map forms used by Lena and Max, including earthworm distributions in (a) the garden, (b) the pond area, and (c) the playing field perimeter using the iconic data (all counts for the variable) and the map form to show location and shade patterns.

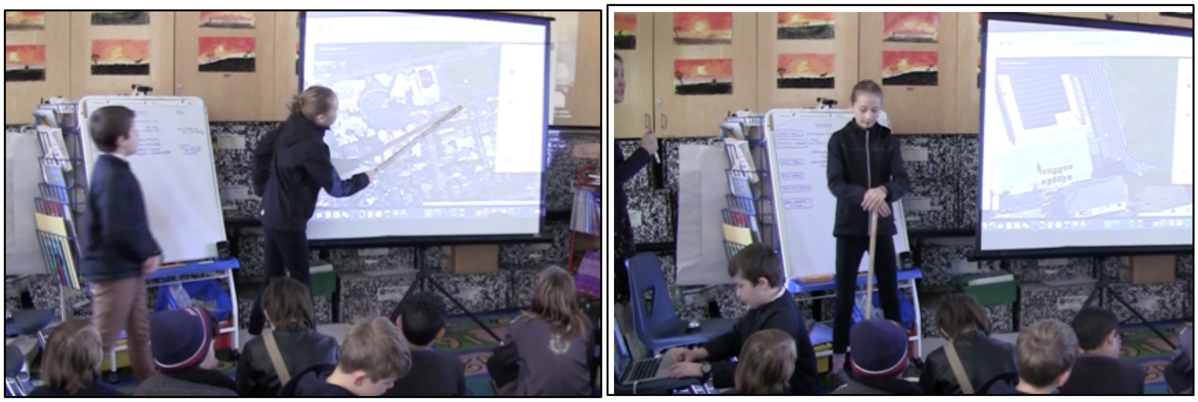
As the pair shares their opening conjecture, Lena and Max use the map form, the iconic data form, and gestural forms to argue that earthworms prefer not only moist soil and roots but also shade. As they shift the location of the map, Lena draws upon her schoolyard knowledge of shady places as she gestures to locations on the map, including garden, the pond area, and her second sampling site near the sports field. In these moments, the pair coordinates a wide array of resources, including their everyday knowledge of the schoolyard (sunlight and shade patterns), their experiences collecting data at their particular site ("the shade from the decomposing lavender bush and the cherry tree"), the iconic data forms (earthworm counts at all 24 sites) and different map forms (shifting locations and zooming in, from garden to pond to sports fields). Such coordinated activity reveals how the GIS maps may support students as they consider the relationships among multiple variables, including variables that are challenging to represent, such as shade. This coordination also makes visible students' everyday knowledge, where schoolyard experiences across the day can meld with collective sensemaking through complex data about ecological processes and relationships.

***First counterclaim: There isn't really shade there*.** Lena and Max next open up the discussion for questions and comments, with Ms. I, the K-5 science teacher, saying that Marcel has noticed an important break in their pattern. Marcel begins, saying "So right now the cherry tree is really bare (*pointing towards the map*) so there is still is a lot of sun there and you said that places where there is shade [is important] and so it is not providing barely any shade." Lena responds quickly, saying "Yeah but well, our lavender bush is creating lots of shade." Lena continues to elaborate with her back to the map, using extended gestures to clarify her site location, show children's everyday foot traffic patterns in the area by marching her fingers (Figure 14a) and depict shade cast by the decaying lavender bush at their site using outstretched arms (Figure 14b).


(a) *(b)*

Figure 14 (a, b). Screenshots of Lena's gestures, as she shows her sampling site from an on-the-ground perspective. She first depicts (a) children's movement through the space using marching finger motions. She then depicts (b) the shade cast by the nearby bush by extending her arm.

Lena then turns abruptly to the map and says, "See this one [plant], right here… see, it is super full" as she moves the pointer stick and then her own hand to land on the specific location on the large map (see Figure 15a). Max simultaneously moves back to the laptop, zooming in the map to show their site's location and plants in closer view (see Figure 15b).



(a) (b)

Figure 15 (a,b). Lena's map use. Lena points to her sampling site (a), referencing her everyday knowledge that shade is provided by nearby plants while (b) Max moves to the laptop computer that controls the map, using it to zoom into their exact site.

In this first counter claim, Marcel uses the map form to ground his discussion of shade (or lack thereof) in the specific sports field location that he knows from his everyday schoolyard experiences. He draws on his knowledge of this particular spot during the winter months ("So right now, the cherry tree is really bare"), noting that the tree leaves haven't emerged yet to provide shade. Lena refutes Marcel's counter claim, first using extended gesture and then the map form to coordinate and communicate her everyday knowledge that the lavender bush does in fact offer sufficient shade. At the same time, Max uses the laptop to change the scale of the map to make their sampling site by the sports field more visible to classmates sitting on the rug.

Second counter claim: My data tells a different story. Lena and Max then call on another child, Ellis. He uses his group's site data (accessed through use of the map) and his and his partners' first-person experiences collecting this data to refute Lena and Max's earlier proposed relationship between worm count, soil moisture, roots, and shade, ultimately changing the map to show related variables in the iconic data and shifting the color map form to his garden site.

Ellis begins, "Well so, I actually kinda disagree with this because like, first of all, our group, we basically have the same circumstances as you… we have a lot of shade, we have moist soil, and we have roots down there too and we've only found one worm so far and we are in that tucked away corner in the garden." Invited by the teacher "to come show us", Ellis then moves up to the laptop, shifting the map view to his garden site, with relevant variables clicked on to include soil moisture and earthworm counts (see Figure 16).

Figure 16. Ellis, crouching on the ground in the near left corner of the photo, changes the map. He changes the map location to the school garden and selects two iconic variables including earthworm counts and soil moisture. Lena and Max stand near Ellis, asking further questions about plants at his site and soil quality.

Responding to Ellis's counterclaim, Lena walks back and forth for several paces, then blurts out: "But did you have a decaying bush at your site?" Max quickly adds in, "What she means is did you have humus at your site?", referring to the rich soil often created by decomposing plants. Ellis replied he doesn't have a lavender bush and the discussion abruptly stops as the recess bell rings.

In this second counter claim, Ellis uses his first-person experiences collecting data and the iconic map forms to contest Lena and Max's conjecture, providing refuting data from his own site. He holds four variables constant with Lena and Max's data (soil moisture, shade, earthworm counts, roots) and notes important variation in findings with one variable, earthworms. This type of work with data has been shown to be challenging for children working with canonical forms (Kuhn & Dean, 2005).Encouraged by the teacher to show the group, he moves the map from Lena and Max's field site to his group's field site in the garden, selecting the soil moisture and earthworm iconic data. Lena and Max try to refute this counterclaim, drawing on their first-person data collection experiences where they observed one plant, a rotting lavender bush providing shade. Shifting map forms (iconic data, color photo map, spatial map) and first-person data collection experiences are both drawn on in this interaction to contest and counter contest evidence and claims.

Summary of case a. In this case, Lena and Max raise an important but challenging-to - represent variable in ecological systems, shade. As students consider and contest the pair's claim, they draw on their class's cross-site data, everyday schoolyard knowledge, and data collection experiences to reason about earthworm needs in relation to the schoolyard environment, considering multiple variables at several different sites. Different map forms (e.g., iconic data form, map form) are used to serve different functions in conversation (e.g., explore relationships among several variables, communicate everyday knowledge). The shifting form-function relations afforded by the map support students' integration of their schoolyard knowledge and their experiences collecting and transforming the data in argumentation and sense making. Further, the combination of individual and shared experiences in this exchange provides students with multiple entry points into the collective discussion, where evidence and claims are conjecture and contested.

Case B: Ellie and Luis's invertebrate and soil moisture conjecture (class 17, pair 6, 22:30 - 35:00). In their presentation, Ellie and Luis conjecture that invertebrates other than earthworms need moist soil. As students consider and contest the pair's opening claim, students draw on the class's cross-site data and their data collection experiences to reason about invertebrate needs in the pond area. Throughout the discussion, students use different forms (iconic data representations, qualitative representations of data and map forms) to serve varying discursive functions. Such coordination using shifting map forms supports students' attention to the unique needs of other "hard-shelled" invertebrates, and the potential that these organisms' needs may be met in different niche environments of the schoolyard.

My analysis of the case is organized in several sections (see Table 10). First, I consider earlier discussions that had largely ignored invertebrates other than earthworms and their potentially different needs. Second, I analyze three segments of the this pair's presentation consisting of several counter claims and ensuing discussions related to Ellie and Luis's initial conjecture. In the first counter claim, a student, Isaac, contests the pair's claim, drawing on the iconic data forms to argue that the class's data actually shows low counts of invertebrates at moist soil sites, not high counts. In the second counter claim, two other students, Kevin and Mary, contest Isaac's claims. In doing so, they draw on their own data collection experiences, using their site results (e.g., dry soil and low invertebrate counts at Mary's site, moist soil and high counts at Kevin's site) to counter Isaac. In the third segment I examine, the class discusses the two "weird" planter sites where lots of invertebrates have been found, with Ellie drawing on qualitative data forms to learn more about these two sites. The discussion concludes by focusing on a key idea in ecology, that different organisms have different needs meet in different niche environments (Lehrer & Schauble, 2012). Across these different segments, I analyze how students use the map's many forms to coordinate their different experiences as they reason with the aggregated cross-site data about complex ecological relationships.

Context for Ellie and Luis' presentation on non-earthworm invertebrates. Prior to Ellie and Luis's presentation, all pairs' presentations (pairs 1-5) had focused on earthworms and potential variables contributing to different earthworm counts. Yet when Ellie and Luis present, they focus on all the other non-earthworm invertebrates counted and recorded during field site sampling, represented as "other invertebrates" in the iconic data. As the pair gets ready to present, they focus the map closely on the pond area of the schoolyard, clicking on two out of the four variables (soil moisture and other invertebrates). Luis states their claim: "Most of the invertebrates here *[pointing to the garden sites*] are in moist soil, like the wetter soil. Not dry soil. They need the moist soil." The ensuing counter claims and discussion focus on these invertebrates' needs.

Table 10

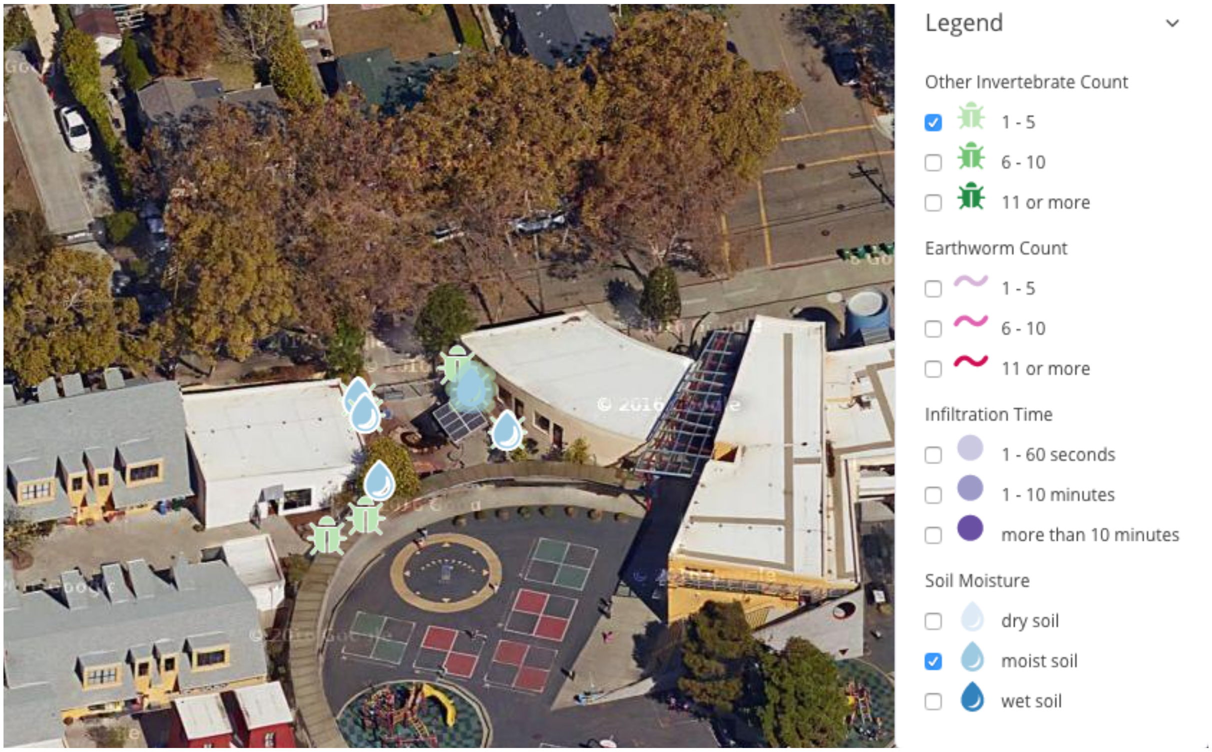
Summary of Ellie and Luis's Presentation Segments.

This table shows students' conjectures and counter claims as well as shifting map forms and experiences drawn upon. [Class 17, Pair 5, 22:30 - 35:00]

Segment	*Students' Claims*	*Drawing on*	*Forms Used*
First counter claim made by Isaac [28:00-29:02]	The data shows low counts for invertebrates at moist soil sites, not high counts	Cross-site aggregated data	Map form Iconic data form
Second counter claim made by Kevin, Mary [29:03-29:50]	Invertebrates actually do need moist soil	Data collection experiences	Map form Gesture
Investigating outliers, involving Isaac, Ellie, and other classmates [29:50 – 35:00]	The data does support my claim, unless you count the "weird" planter	Cross-site aggregate data Data collection experiences	Map form Qualitative data form

First counter claim: The data tells a different story. Luis and Ellie have just stated their opening conjecture - other, non-earthworm invertebrates need moist soil. Several classmates' hands shoot up while Luis is talking and Ellie adjusts the map to show their data and location more clearly. Isaac is the first child called on by the pair. He contests the pair's claim, arguing that most of the low counts for invertebrates are at moist soil sites. Isaac requests the interactive GIS map be adjusted to explore his conjectured relationship more carefully.

> Isaac: So you were talking about the invertebrates needing moist soil. But if you go to the pond (*pointing at the map and talking to Ellie)* and turn on the moist soil and then turn on 1-5 invertebrates and you see (*pointing at the iconic data map form,* Figure 17), you'll see that almost every single 1-5 [invertebrates] is at moist soil. So I kinda disagree because you said oh, they need lots of moist soil! But here, as you can see (*pointing at the map),* there are lots of 1-5 [invertebrate counts], which is actually not a lot [of invertebrates] in the moist soil area.



Legend

Other Invertebrate Count
☑ 1 - 5
☐ 6 - 10
☐ 11 or more

Earthworm Count
☐ 1 - 5
☐ 6 - 10
☐ 11 or more

Infiltration Time
☐ 1 - 60 seconds
☐ 1 - 10 minutes
☐ more than 10 minutes

Soil Moisture
☐ dry soil
☑ moist soil
☐ wet soil

Figure 17. Isaac's requested map, showing earthworm and soil moisture data "turned" on by being clicked in the iconic data panel on the right. Notice how the moist soil sites overlap with many of the 1-5 invertebrate sites, obscuring the invertebrate symbol.

In this first counter claim, Isaac requests changes to the iconic data forms, focusing only on one subfield of the invertebrate data, the 1-5 invertebrate counts. Using this narrowed data, he then highlights how these relatively low counts of invertebrates are often found at moist soil sites. He uses this pattern of co-variation, among low invertebrate counts and moist soil sites, to contest Ellie and Luis's opening conjecture.

Second counter claim: Invertebrates actually do need moist soil. Other classmates' join in, responding to Isaac's counter claim. Two students, Mary and Kevin, draw on their first person experiences collecting data at pond sites, raising disconfirming evidence to Isaac's point. Mary argues that soil moisture isn't that important, drawing on her own site that had low invertebrate counts and dry soil as evidence. Kevin agrees with Mary that soil moisture isn't determining invertebrate counts, drawing on his site data where he found lots of invertebrates and actually had moist soil. Attention then shifts to understanding two outliers, the "weird" planter sites that have very high invertebrate counts and moist soil.

Mary: I don't feel that is honestly true. Just because I didn't (emphasis) have moist soil and I found only 4 invertebrates.

Kevin: I also agree with Mary 'cause I had, in the planter where I was (*pointing towards his site on the map*), I had 110 invertebrates in my site and the soil was moist.

Isaac: I'm just saying on the moist soil, there isn't going to be a lot of invertebrates unless you count their ol' planter (referring to Kevin's site), that one that had a weird amount, a lot (emphasis) of invertebrates.

Analysis. In this second counterclaim, two students contest Isaac's counterclaim. They draw on their first-person data collection experiences. Mary uses her site's low invertebrate counts and dry soil to dispute that soil moisture plays a role in invertebrate numbers. Kevin uses his exceptionally high invertebrate counts to argue that moist soil and invertebrate might be associated after all. Isaac concludes that his counterclaim still stands, as long as you exclude Kevin's unusually high count.

Investigating outliers: Exploring the "weird" planter sites in depth. The conversation then shifts to understanding the two outlier sites in more depth, focusing on their location in the schoolyard.

Kathryn: Isaac brings up a good point. He is talking about this kinda complex thing which is 1-5 invertebrate, then you go up to 6-10, then you have what Kevin and Maurice found in their planter – they has 11 or more. But one of the things that Ms. I and some others kids raised before is that maybe Kevin and Maurice's planter is unique, because it is the only planter we studied.
Class: Yeahs, Un-huhs called out.
Kathryn: Wait, did anyone do a planter for their second site?
Maurice: Yeah, Luis and Ellie!
Kathryn: Oh, Luis and Ellie. What did you find at your site? Will you show us? Maybe there is something about planters that supports lots of invertebrates?

Ellie then clicks on their second sampling site, opening up their qualitative data layer that included the pair's photos, sketches and text notes. Ellie scrolls through the different photographs and sketches (Figure 18a). Next, she scrolls down to their text notes below (see Figure 18b).

team name:
infiltration rate:
soil color: dark brown
kinds of invertebrates: 6 gnats, 20 ants, 4 tiny bugs
soil moisture: wet
soil composition: twigs, rocks, plants, more soil
roots: yes
earthworm count: 0
team number: 4
other invertebrates count: 30

Figure 18a. Ellie and Caleb's site, showing qualitative form (sketch) in upper left corner

team name:
infiltration rate: 286
soil color: dark brown
kinds of invertebrates: 6 gnats, 20 ants, 4 tiny bugs
soil moisture: wet
soil composition: twigs, rocks, plants, more soil
roots: yes
earthworm count: 0
team number: 4
other invertebrates count: 30

Figure 18b. Ellie and Caleb's site, showing qualitative form (text notes) on left side panel
Figure 18 (a, b). Ellie's use of the qualitative data forms, showing first (a) sketches, then (b) text notes including invertebrate species notes, raw infiltration times, and other typed notes about the site.

Kathryn: What did you find? [*as Ellie scrolls down to text notes on the map*]. Whoaa! Look at this! We are on to a pattern. Luis and Ellie, it looks like you found lots of invertebrates, many of which were small, just like Maurice and Kevin!

Ellie: See, we had a lot too! Maybe there is something about the planters that the other invertebrates like?

After a ½ minute duration of excited overlapping talk among the class, two students draw on their own data collection experiences at their sites, agreeing with Isaac's claim that moist soil isn't helpful for all invertebrates. A third child adds in, noting an inverse relationship between earthworms and other invertebrates, requesting that the map be changes to show invertebrate and earthworm distributions only.

In this exchange, Ellie uses the *Local Ground* qualitative data form to show more information about her pair's second sampling site, revealing a similar high invertebrate count to Kevin's site. The combination of the map form (showing the spatial locations of the two "weird" sampling sites) and the qualitative forms (showing the original counts and text notes at Ellie and Luis's site) appears to help students in making sense of two planter sites with unusually high counts. Importantly, the combined use of forms also supports students in reasoning about a key idea in ecology, namely that different organisms have different needs met in distinct niches within a system (Lehrer & Schauble, 2012).

Summary for case b. Across this case, the interactive GIS maps supported students coordinating their data collection experiences and the cross-site aggregated data, enabling students to conjectures and contest evidence and claims. The maps also supported students in digging deeper into two puzzling outliers in their data and attending to a key idea in ecology (needs met in different niches). In this case, we see Luis and Ellie use the iconic data and map forms to support their conjecture that invertebrates other than earthworms need moist soil. Isaac contests this claim, shifting the iconic forms to show only a subset of the invertebrate and soil moisture data (e.g., 1-5 invertebrate counts and moist soil only). In turn, Mary and Kevin contest Isaac's claim, drawing on their first-person data collection experiences sampling at their pond sites. In trying to understand the high counts at Kevin's planter sites, Ellie shifts the map forms again, using the qualitative data form to gain more specific information about the pair's planter site. Throughout, this blending of data forms (iconic and qualitative), the map forms, and first person experiences collecting the data at field sites supports robust work with the data and important insights into their schoolyard ecosystem.

Subsection Section II: Students' Use of Other Forms to Coordinate Data and Experience: Two Cases. Although the Local Ground maps were often drawn on in discussion, there were times when students did not use the maps as they drew upon and integrated their everyday schoolyard knowledge with their data collection experiences in argumentation and sense making. In these instances, students used other forms, such as verbal talk and gestures. These improvisations of form-function relations were often in response to either limitations of the *Local Ground* mapping tool design or the inherent complexities of reasoning about a complex ecological system across multiple sampling sites and temporal durations (e.g., days, weeks, seasons, years). For example, at times students wanted to shift to on the ground perspectives, imagining themselves on a spot on the map looking around (street view). When such a perspective was needed, students drew on forms external to the map to support coordination and argumentation. Additionally, at times students wanted to talk about dynamic mechanisms and processes not visible in the data. In reviewing instances of non-map coordination, the map was replaced with other forms in one of three contexts:

Context #1: Consensus established about claims and evidence. One context of non-map use was when the relationship being conjectured was relatively clear in the data and agreed upon by the group, thus warranting little need to return for additional evidence or to engage in gesture.

For example, after the second cycle of data collection and transformation, a strong relationship had emerged in the aggregated class data showing higher earthworm counts co-occurring in moist soil. This was evident across data representations (e.g., bar chart, interactive GIS map) and across both data collection cycles. As a result, if pairs elevated this relationship in their presentation, it was discussed relatively quickly with no map use or gesture, and often very little coordination as well.

Context #2: Focusing on mechanism. A second context was when the classes' conversations shifted to explaining underlying mechanisms that would account for observations and quantitative data. For example, as students discussed why soil is compacted in specific locations, students attributed its compaction as resulting from their recurring footsteps over at the site. To convey such accounts of dynamic processes, children tended to rely on communicative gestures and verbal description. Case C offers an example of this.

Context #3: Focusing on sampling methods and detailed properties of schoolyard sites. A third context involving coordination but no map use occurred when children needed to provide a detailed depiction of the schoolyard spaces or the sampling methodologies. For example, as children described particular sampling sites or schoolyard spaces, they often shifted away from the map, instead using extended gestures to show the relationship between build structures, human activities in the spaces, and plant species from an on-the-ground, "street-view" perspective. Additionally, as children clarified and questioned sampling methodologies used in recording data at schoolyard sites, children re-enacted their sampling activities and procedural steps (e.g., showing depth of digging at site with hands or their step-by-step procedures of placing the tin can, pouring water, and timing the infiltration rate to measure infiltration rates). Case D offers an example of this. Also recall Case A, where Lena used extended gesture to describe her second sampling site. This included gestures to describe students' movement and the arc of shade created by her decaying lavender bush.

In the cases that follow, I present two cases that reflect the contexts described above. In Case C, the presenting trio moves to mechanistic explanations, to explain the interdependent relationship among earthworms, soil moisture, soil temperature, and the worms tunneling activities (Context #2). In Case D, the presenting pair shifts to gesture to provide a detailed depiction of their sampling site, a hidden garden site (Context #3).

Case C: Myisha, Nora, and Rosalina's soil temperature and moisture conjecture (class 17, pair 7, 37:10-44:30). In this case, Myisha, Nora, and Rosalina put forth a new conjecture: that earthworms don't just like moist soil but also dry soil, arguing that soil compaction and the temperature of the soil might be important aspects to consider as well. As students consider and contest the trio's opening claim, students draw on their data collection experiences and gesture to reason about how these multiple variables are interdependent as the discussion focuses on causal explanations about mechanisms.

In this case, I examine a small slice of Myisha, Nora and Rosalina's presentation. First, I present the foregrounding discussions that occurred. Second, I analyze a segment of the presentation, where the trio and classmates turn away from the map as they discuss potential mechanistic explanations coordinating multiple variables. In this segment, Rosalina offers her initial conjecture that soil moisture and temperature are important to worm's tunnel stability and structure. Several students contest this claim, considering earthworm needs, the relative difficulty of tunneling through different soil types, and temperature. Across this segment, I analyze how students use gesture and verbal utterances to coordinate their data collection experiences and reason about mechanistic processes.

Context for Myisha, Nora and Rosalina's presentation. Prior to the trio's presentation, students had discussed relationships among earthworm counts, soil moisture, and soil compaction levels. Yet this was the first and only presentation focusing on temperature, a new variable. Additionally, it also was the only discussion that considered how earthworms' tunneling activities potentially might be intertwined with several other variables. Such considerations, of the multi-directional relationships between living and non-living parts of a system, are at the crux of ecology studies (Lehrer & Schauble, 2012).

Rosalina:	What I was thinking is that worms don't just like moist soil but they also like dry (extending word) soil.
Kathryn:	Hmmm. Tell us about that. Why, what makes you think that in your data?
Rosalina:	Because they need like compacted dirt [*gesturing downward with her hand to show compaction process, Figure 19*] something to hold their tunnels up. You can't just crumble to the ground. But also when you have dry dirt, that isn't wet, it can stay cool.

Figure 19. Rosalina gestures downward to show soil compaction process.

Myisha, Nora, and Rosalina then open up to the floor for classmates' questions or comments.

Darius:	Well if they have dry soil, worms need to stay moist to survive. It might not have enough water to let them stay moist, er wet.
Gal:	I disagree because I feel like if its' gonna be too dry, then its going to be hard for them to tunnel. And if it is moist, it's already softer and easier to tunnel.
Myisha:	Dry soil is like staying in the sun for worms. Worms need the moist soil. If they don't have it, they could fry! They HAVE (emphasis) to stay moist so they can get around. Like at our spot!
Elizabeth:	Maybe the worms make the soil moist (mumbled softly).
Kathryn:	Ahh, Elizabeth just said something. She said maybe the worms make it most. Maybe there is something about the worms that makes it moist?
Myisha:	How'd the water get there then?

Jacob: I disagree with that, cause I don't think worms can produce water, or something else.

Elizabeth: Maybe the worm's tunnel makes the soil looser, and allows water to soak in better (*moving her hand in a zig- zag downward motion).*

In this segment, the map is backgrounded as the principal representational form as students focus on causal explanations of underlying mechanism, describing interdependent relationships among multiple variables. Instead, students rely on descriptive gestures and verbal descriptions as they offer accounts of how earthworms, soil moisture, temperature and soil compaction might all be intertwined. As children conjecture and contest possible explanations, Myisha connects these broader processes to her data collection experiences at her sampling site where her group found few earthworms in their dry soil garden site. Both Rosalina and Elizabeth use gesture to depict processes underground. Rosalina uses it to embellish her descriptions of soil compaction. Elizabeth uses gesture to show water moving further underground through the earthworm's tunnels. In this discussion, students are coordinating and considering multiple dimensions of the soil environment (soil moisture, soil compaction, temperature) as well as earthworms' movement through underground spaces (tunneling). They also are considering temporal timing of these interactions, such as soil becoming more compact as it dries and earthworms' tunneling activities influencing how water percolation processes.

Summary of case c. In this case, students temporarily shift away from manipulating and referencing the map as they engage in mechanistic explanations involving multiple biotic and abiotic variables. In this instance, and several other instances involving mechanistic and causal explanations, students map use often gave way to elaborated gestures to show processes and interactions unfolding over time.

Case D: Priya and Isaac's tucked away garden site (class 18, pair 10, 12:50 - 31:20).

In this case, Priya and Isaac present their garden site data to contest a consensus building in prior class discussions using the aggregated data: the emerging consensus is that there is relationship between greater soil moisture and higher worm counts. As students consider and contest the pairs' opening claim, Isaac draws on his first person data collection experiences and everyday knowledge of the schoolyard gesture to describe the unique features of the garden sampling site.

In this case, I examine Priya and Isaac's presentation where the pair shifts away at one point from using the map as the principal representational form. First, I consider earlier presentations where consensus is building that there is a relationship between higher soil moisture and earthworm counts, a conjecture that Priya and Isaac contest using their own site. Second, I analyze one small slice of the presentation where Isaac shifts to descriptive gestures to show more details about their garden site from an on-the-ground, "street view" perspective in contrast to the larger GIS maps' birds eye view. Using his hands, he recreates the garden space, showing the physical proximity of the walls and students' common walking paths in that space. In the process, he draws on his first-person experiences collecting data at his site and also his everyday schoolyard experiences being in that garden space across different points in time.

In prior discussions, students had noted a strong relationship, between earthworms and moist soil, with other pairs suggesting roots and shade were important as well (e.g., Pair 2: Mia and Taye, Pair 3: Lena and Max, where Isaac contests the pair). Yet Priya and Isaac contest this claim, making the following argument: Despite having moist soil, shade and roots, they only found one earthworm at their hidden garden site. Earlier in the pair's presentation, Priya and Isaac drew upon the map's iconic data representations including multiple variables (soil moisture, earthworm data, infiltration time). Yet as the discussion continues, students ask about additional aspects of their garden site to understand their discrepant data.

> Marie: "Do a lot of people walk around there?"
> Isaac: "In our area? *(as he points towards the map).* Not at all! It actually is in a tight little corner."

Isaac then continues, stepping away from the map and orienting his body towards his classmates on the rug below. Using gesture to provide an on-the ground "street view" perspective on their sampling site, Isaac says, "Because ours [our site] is like … See, the classroom is here, actually here (see Figure 20a) and this wall is here and our site is far from where kids walk a lot (*shifting his hands to show his groups' site from a different perspective*, see Figure 20b).

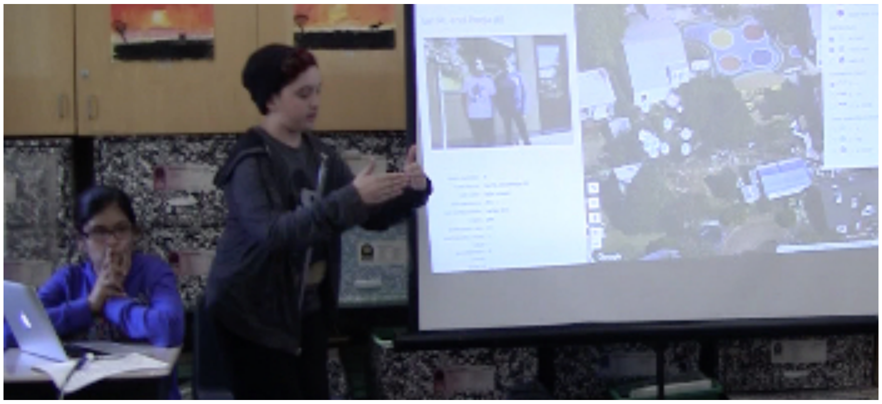


Figure 20(a). Isaac's initial gesture depicting their garden site, facing towards himself.

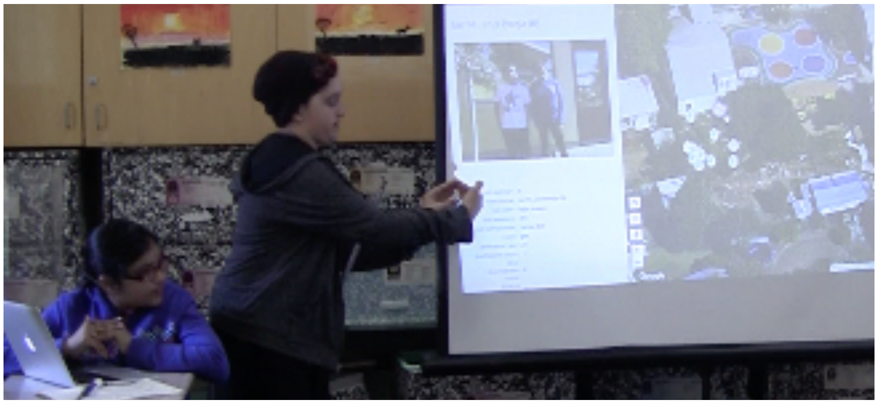


Figure 20(b). Isaac's at the end of a series of gestures, depicting his actual site location in relation to students' everyday foot traffic and the school building wall from a first person, "street view" perspective. He has turned his body to make his depiction of their sampling site more visible to his classmates on the rug below. Priya sits at the laptop, controlling the interactive map screen yet making no adjustments during this time span.

In this segment, the map is replaced as the main representational form. Instead, Isaac relies on descriptive gestures and verbal descriptions to offer an on-the-ground, “street view” perspective of their garden sampling site. This shifted perspective enables Isaac to recreate his tucked away garden site, depicting the built structures (e.g. “the classroom in here”) and children’s movement through the space (e.g., “where kids walk a lot”). In the process, he coordinates and communicates his first-person experiences collecting data and his everyday experiences being in that garden space as he reasons about earthworms needs in the schoolyard.

Summary of case d. In this case, students momentarily shift away from using the map as the central representational form. In this instance, and several others instances where students need to change perspectives on the schoolyard space, students instead use elaborated gestures. In doing so, they coordinate and communicate knowledge about the built structures, human activities, and natural processes into the collective discussions about the schoolyard ecological system, leading to careful consideration of multiple variables in an ecological system.

Discussion

In this chapter, I set out to examine *if* and *how* late elementary students would draw on their "everyday geographies", their experiences collecting and transforming data, and their aggregated cross-site data using the digital interactive GIS mapping tool as they conjectured and contested relationships and explanations about an everyday ecological system, the soil ecology underfoot in their schoolyard. In examining the three class sessions, I found students did indeed make frequent and inventive use of their everyday schoolyard knowledge and their experiences creating and critiquing data across two inquiry cycles, using the maps as well as other forms to reason about ecological relationships and processes in collective science discussions.

In the paragraphs that follow, I focus on what types of interactions and reasoning became possible when students coordinated their first person experiences and aggregated cross-site data across space and time, with attention to students reasoning about ecological systems and processes. I focus on both opportunities and challenges that emerged as students conjectured and contested evidence and claims about their schoolyard ecology underfoot. I conclude by discussing implications for the design of digital map tools and science curriculum,

Coordination using the map. Across the 11 pairs' presentations, students used different map forms to serve different functions as they conjectured and contested evidence and claims. The maps provided a context to both communicate ideas with classmates and also supported student sensemaking in terms of coordinating their everyday knowledge and their data collection experiences. In the process, students were able to dig deep into the data and meaningfully leverage their everyday experiential knowledge, in turn understanding ecological system processes and interrelationships in more critical and nuanced ways.

Going deep into the data and context. One generative aspect of students' coordination using the map is that it supported going deep into the data, exploring complex multi-variate relationships and examining puzzling outliers. These conceptually rich engagements with data often led to key ideas in the ecology, such as understanding that different organisms have different needs met in different niche environments (Lehrer & Schauble, 2012). For example, in Luis and Ellie's discussion, students were able to move from first exploring a spatial distribution of invertebrates in a small subset of the schoolyard, then considering possible covariation with soil moisture data and then "returning" to two particular sites and their qualitative data (e.g., text notes, photos, exact numerical counts) to understand notable differences in invertebrate counts. In the process, students used varied forms to support in the moment functions, leading to important insights into different organisms' needs and the conditions within which they best thrive. Similarly, in Isaac and Pirya's presentation, students were able to consider multiple variables simultaneously, attending to the difference in one variable (e.g. earthworm counts) at two sites. This type of comparison is a challenging movement for students to make in science inquiry (Kuhn & Dean, 2005) yet one that occurred multiple times across the three class sessions analyzed. This movement also spurred an extended discussion evoking additional dimensions of the schoolyard environments (e.g., foot traffic pathways, plants' growth and health) and a critical eye towards the uniformity of sampling methodologies enacted by pairs, leading to a nuanced coordination of data, experience and environment as students conjectured and contested what earthworms really needed in order to thrive. This depth of engagement occurred in coordination with the interactive GIS maps, where they functioned as a collective canvas where varied data forms and experiential knowledge could be integrated.

Elevate the everyday. Students' map use also supported elevating and making visible to others students' their everyday schoolyard knowledge. From shadows cast by buildings or by a now bare cherry tree to daily foot traffic pathways of children on their way to Physical Education classes to shallow spaces often flooded in the rainy season, students' multi-modal knowledge of their "everyday geographies" was frequently leveraged and most important, made visible to others and overlaid on top of the iconic data. For example, shade was not only verbally elicited but through Lena's hand gesture, the area and spatial positioning of the shade could also be made expressed in relation to earthworm counts. Additionally, other moments included students running their fingers along the surface of the map to show foot traffic patterns common to children's "daily rounds" or pointing to play spaces prone to flooding during the rainy season. Using the map in this process, richer depictions of the schoolyard space were made available to fellow classmates, supporting a nuanced understanding the schoolyard space and place across varied time frames were accessible, as a backdrop to understanding the aggregated data. In studies of ecology, many important dimensions of the environment are challenging to make visible, with ecologists' often depending on field notes or their own extended field experiences to reason about data and underlying processes (Latour, 1999; Roth & Bowen, 2007). Here, students were supported in bringing forth and sharing this knowledge and using it to conjecture about ecological systems not just in that moment but over weeks and seasons. First-person experience not only had a place in the classroom discussion but could be grounded and make visible for others to see as students conjectured and contested evidence and claims.

Coordination using other forms. In addition to the GIS maps, students drew on other forms as well to support their coordination of their everyday schoolyard knowledge and data collection experiences, supporting reasoning about ecological systems across space and time. Students' descriptive gestures were a powerful resource in (a) bringing forth, making visible, and sharing their first-person everyday schoolyard knowledge in collective sense making with the data and (b) considering underlying mechanisms and explanations for relationships emergent in their aggregated data. Consider Isaac's experiences depicting and sharing elements of hidden gardens sampling site (Case D). Isaac uses extended gesture and verbal communication to depict and share the daily walking pathway of children and the angles of school building walls to clarify his unique garden site. His everyday knowledge of children's daily pathways through a garden and the angles of building walls was not only made available in collective discussions but it also supported the larger purposes of understanding discrepant findings at two sites across multiple variables. These findings connect with existing research arguing that maps need to be studied and understood with a broader "semiotic ecology", with work focusing on collective activity in small group work in classroom-based settings (Enyedy, 2005; Radinsky, 2010) as well as extending beyond the classroom walls and across longer time durations (Headrick Taylor, 2013, 2017; Leander et al., 2010).

Students' gestures were also a resource in students' reasoning about underlying mechanisms, coordinating multiple interacting parts across time and space. For example, in Case C, Myisha, Rosalina and Nora's extended discussion centers several variables (e.g., soil moisture, soil compaction and temperature), with gestures elaborating potential processes and mechanisms. Such findings are consonant with existing work on gesture in science and mapping disciplines where Mathayas, Brown, Wallon and Lindgren (2019) have shown gesture to be a key resource in students' reasoning about causal and mechanistic processes. Such findings also connect with Flood, DeLiema and Abrahamson (2018)work showing the integral role of gesture to make invisible, dynamic phenomena and processes visible for others in collective discussions.

Theoretical and methodological approach. Saxe's form/ function framework offered a useful theoretical and methodological approach to studying *how* digital technologies can be adapted and transformed in use as part of classroom disciplinary activity. By focusing on different forms, and the function they serve in collective activity, this methodological approach made it possible to closely examine how specific design features of the *Local Ground* maps were used in students' sense making with data. Analysis using this framework also illuminated the way the GIS maps and other representational forms afforded students opportunities to draw on their "everyday geographies" and their data collection experiences at local sites to reason about aggregated data. It also offered an interactional view of students' science argumentation processes, where different forms of evidence in varied formats were leveraged to conjecture, contest, and elaborate on evidence and claims raised by peers.

Implications for digital map tool and science curricular designs. In light of this analysis, I argue there are important implications to consider for both the design of digital spatial tools and science curriculum, particularly for elementary age students.

Digital map design implications. As noted above, the interactive GIS map was often a generative resource for students, as they reasoned with the cross-site data about relationships and explanation in the ecological system. The map also presented challenges for students in communication and coordination. Below I outline several generative and limiting elements of the maps, with an eye towards future designs.

Generative elements. Two design elements appeared to be particularly useful to students in coordinating first person experiences and cross-site aggregated data across space and time - the ability for students to move flexibly between the map and different kinds of data.

Students were able to easily move between creating and critiquing different data map representations, switching readily between different scales and volumes of data. By *scale,* I mean students could consider one particular site and its unique features, a smaller subsection of the schoolyard such as just the garden or the playing fields, or consider the entire schoolyard space. This spatial movement is especially useful in ecology studies for attending to smaller niche environments within larger environments with attention to different resources supporting different organism needs in different contexts (Lehrer & Schauble, 2012). By *volume,* I mean students could explore just one variable at one site all the way to several different variables at one site. This movement, between individual data points and clusters of data points (aggregate), is an important movement in reasoning with and about data in both statistics and life sciences. It also supported students in simplifying or complicating the data as they saw fit, digging deep into one variable or reasoning about multiple variables across several sites. This ability to quickly create and critique so many different arrangements of their cross-site data supported exploring and explaining ecological systems at varied scales and volumes, a movement shown to be important in existing studies of students learning about ecological systems (e.g., Hmelo-Silver & Azevedo, 2006; Hmelo-Silver, Marathe, & Liu, 2007) as well as sensemaking about socio-mathematical processes (e.g., Rubel et al, 2016; Wilkerson and Lania, 2018).

The overlapping of data and maps often supported a notable blending by students of context, experience and data in collective sense making. Students often had an ability to explore relationships among multiple variables in varied data formats, all the while the data remained anchored to the original context in which the data was gathered by students. For example, as

Lena discussed the spatial distribution of earthworms in the schoolyard using the iconic data forms, she integrated her experiential knowledge of sunlight and shade patterns across the schoolyard into her reasoning about earthworm counts and conjectures about earthworms' needs. This overlap often supported a blending between students' embodied, multi-modal experiences out in the schoolyard across days, weeks and seasons and their reasoning about ecological system interactions as they worked with various data forms. This overlap of data and experience across time and space connects to Headrick-Taylor's recent work (Headrick-Taylor, 2017), where she proposed a new analytic unit, *learning along lines*, to examine how youths' sense making with inscriptional forms is enmeshed in their movement out in the city using maps. In this chapter, I build on this scholarship of mapping, mobility, and data, with a contribution of exploring these interactions with elementary students and within science disciplinary pursuits.

Limiting elements. There were also two prominent limitations of the GIS map tool that emerged for students. These included limits on adjusting the scale at closer ranges and limits shifting perspectives from a bird's eye to an on-the-ground perspective. Both of these limitations stem from the Google map interface design being used as the basis for the map making and the design choice on my part to focus on a schoolyard space at closer scales. In terms of scale adjustments at closer range, students could not zoom in further than approximately 50 feet off the ground (a scaling limit established by Goggle maps). As result, there were times when students bypassed the map to show or clarify a closer view of the schoolyard (as in the case of Lena (Case A) where she used gesture to describe her sampling site's plants' position in relation to the field area or Isaac (Case C) using gesture to describe his small, hidden garden site). In these instances, students "zoomed in" further using gesture, to recreate and describe the particular locale in greater detail. In terms of map perspectives, students often wanted to take an on-the ground, "street view of the schoolyard space as they reasoned about the data and conjectured relationships and explanations. Although shifting perspectives is a supported feature of Google maps (e.g., StreetView), students were not able to use this feature because they were exploring an area enclosed and way from the street, making this on-the-ground perspective inaccessible using the map (despite several attempts by students).

In future work, it would be generative to consider workarounds and additional mapping technologies that might support this shifting of scale and perspective that students in the study often wanted to enact. This seems especially important for younger students, who are newer to cartographic conventions that entail taking a bird's eye view (e.g., Enyedy, 2005b; Liben, 2001; Myers & Liben, 2008) and who also experience scale, space and place in different ways than older youth and adults (e.g., Hart, 1979). Additionally, it would be interesting to consider how interactive GIS mapping might be complimented by mobile augmented reality (MAR) technologies, which support mobile, on the move juxtapositions of data and context from an on-the-ground first person experience. For example, Ryokai and Agogino (2013) used Mobile Augmented Reality (MAR) to support college students' exploring and learning about local ecological systems (forests and stream network). In this work, they documented tradeoffs in youths' reasoning and interactions using on-the-ground perspectives and data layering made possible with MAR technology in contrast to interactive GIS maps, noting potential of future work to integrate the two digital formats, perspectives, and interactions supported by each.

Instructional design implications. Given the prevalence with which students drew on their everyday schoolyard knowledge and data collection experiences - and most importantly, the quality of the reasoning and interactions that occurred, it appears the place-based aspects of this design were generative for children's science reasoning and argumentation. For example, this approach supported reasoning about data in relation to context, an important coordination in ecology studies where the focus is on reasoning about relationship among living and non living parts across space and time. This instructional design approach also supported students coordinating multiple variables, many hard to express and share yet crucial to understanding how ecological systems processes unfold. Additionally, this approach offered students multiple entry ways into conjecturing and contesting using wide range of experiential points of evidence (e.g., feeling, hearing, touching, seeing, daily body movement). In general, students were able to move back and forth between their everyday experiences, data collection experiences and their reasoning with aggregate data, meaningfully moving between individual and aggregate data points to make sense of relationships and conjecture possible explanations using their cross-site data.

Chapter 5
Elementary Students' Engagement with Scientific Practices to Support Systematic Inquiry: Clash and Confluence Rooted in Students' Desires

Chapter Abstract

In K-12 science education classrooms, students are increasingly engaging with scientists' practices in order to support inquiry, critical thinking, and conceptual understanding. The "practice turn" (Ford, 2015) in science education reflects recent curriculum reform documents like the Next Generation Science Standards (NGSS Lead States, 2013) and the National Research Council (NRC, 2012). Nevertheless, to date we have limited understanding of *how* scientific practices are meaningfully taken up and adapted in classroom contexts (Manz, 2015). To further our understanding of students' uptake of practices, I engaged 5th grade students with a 10 week curriculum in which students studied the soil ecology underfoot in their schoolyard and engaged in cycles of ecologists' practices. This included identifying parts of an ecosystem, transforming parts into measurable variables that they collect, and aggregating, visualizing, and discussing their data in partner and whole class discussions. I show, through longitudinal analyses, that students' own desires and interests sometimes led their inquiry activities into uptakes that were aligned with ecologists' sampling and representational practices (confluence), and sometimes created clashes with those practices and the disciplined inquiry functions that they afford. These clashes and confluences in turn opened up different learning pathways, and have broader implications for classroom practice and learning theories.

Introduction

Within science education classrooms and educational research consensus documents (NGSS Lead States, 2013; National Research Council, 2011), there is an increasing emphasis on engaging K-12 students in the practices of scientists. The shift toward practice--what Ford (2012) calls the "practice turn"-- aims to better reflect the social, material, and cognitive knowledge-building activities of scientists within the classroom context. Importantly, the practice focus supports student engagement with a wide range of science activities, from framing questions and considering methods, to data collection, to creating and reasoning with complex data representations. It also leads students to wrestle with the messiness and complexity of scientific inquiry (Manz, 2015), engaging students in the challenge and delight of structuring the ill-structured (Metz, 2008: Metz, 2011). Despite the importance ascribed to engaging student inquiry in practices of science, we know little about *how* science practices are meaningfully taken up in K-12 classrooms, as well as the role of students' own desires and aims in shaping this process.

To advance our understanding of students' uptake of scientists' practices in reform-oriented fifth grade classroom, I observed student interactions within a larger design-based research project on students' investigations of ecological systems (Lanouette, Van Wart, & Parikh, 2016). The lesson sequence centered on the schoolyard soil ecology as a site for inquiry, and engaged children in ecologists' practices to support their inquiry. These practices included identifying parts of the system, transforming parts into variables, and aggregating, visualizing and discussing patterns in the data. The project's curriculum unfolded across two cycles of data collection and varied representational activities. In my analyses, I examined how targeted fifth-grade student's desires and aims were integral to their uptake and engagement in ecologists' practices, sometimes supporting closer alignment with those practices and other times leading to a clash with the intended function of the inquiry practices.

In the sections that follow, I first describe literature on affect and aims in science with particular regard for ecology, focusing on both professional scientists and students. Next, I describe my curricular design that constituted the arena for my inquiry as well as the methods that organized my inquiry. In my longitudinal analyses of two student pairs, I analyze how children's desires were intertwined in their engagement with the ecologists' practices supported in the curriculum, with attention to how children's varied experiences shaped different learning opportunities. Implications for theory and K-12 science practice are discussed.

Affect, Aims, and Desires in Scientists' Practices

Drawing on Science and Technology Studies literature, scientists' ethnographies, biographies and personal reflections, Jaber and Hammer (Jaber & Hammer, 2016a, 2016b) argue that scientists' affect and aims are integral to science inquiry pursuits, constituting part of what instigates and stabilizes disciplinary engagement. Feelings such as pleasure, curiosity, and frustration are bound up with scientists' aims and motivations in activities such as posing questions and examining patterns in data. The authors argue that engagement in science practices involves learning at the level of affect. Jaber and Hammer write: "Taking up the [science] pursuit means, in part, becoming driven by feelings of puzzlement and curiosity, coming to manage and be motivated by feelings of confusion and frustration, anticipating and seeking the joy of a discovery or a new understanding." (Jaber & Hammer, 2016, p. 195). As such, they argue that the affective dimensions inherent to science are inseparable and intertwined with the conceptual and epistemological aspects of science pursuits.

Building on earlier work by Pintrich, Marx and Boyle,(1993), Jaber and Hammer argue for the need to better understanding how affect and aims emerge within science disciplinary pursuits. They make a clear distinction that they are focusing on the "feelings and drives that arise *within* the doing of science rather than feelings *about* science,"(Jaber & Hammer, 2016, p. 199) the latter being the more common approach to studying affect and motivation in science education research. Consistent with situated and socio-cultural approaches to studying science disciplinary pursuits and learning (e.g., Engle & Conant, 2002; Hall et al., 2009), Jaber and Hammer propose the emergent nature of affect in interaction with social, material, and historical contexts.

Jaber and Hammer (2016a, 2016b) note that scientists' aims span a wide affective range, involving pleasure, delight, and curiosity as well as competition, fear, and frustration. The authors describe scientists' joy in discovery, citing biologist Gerald Edelman recalling 'the splendid feeling, almost a lustful feeling, of excitement when a secret of nature is revealed' (quoted Wolpert & Richards, 1997, pg 137) and theoretical physicist Richard Feynman's recalling the 'pleasure of findings things out' (Feynman & Weinberg, 1999, pg. 1). Jaber and Hammer also describe the frustration, competition, and fear of critique that shape scientists' disciplinary interactions. They cite Gruber & Barrett's (1974) study of Charles Darwin's experiences of passion, affect, and interest shaping his Galapagos studies as well as Thagard's (2008) descriptions of Watson and Crick's feelings of fear and competition as they raced to discover the structure of DNA. Collaborations in particular, within and across research groups, are often the source of intense disagreements, many of which center around representational activities and infrastructures (Hall, Stevens, & Torbella, 2002). Moments of frustration and loneliness are also integral to scientists' inquiry pursuits; such as ecologists' field-research experiences working remotely for long stretches and wrestling with tool malfunction (Cotterman, 2016).

Jaber and Hammer's focus on affect and aims connects to earlier work by Pea's (1993) and Vygotsky (1967)in which both discuss affect-laden *desires* as integral to cultural processes of learning. In Pea's writing on distributed cognition and design, he argued for attending to learners' "diffusely specified *desires* that often lead to action" as well as in-the-moment wants and feelings that "shape both their interpretation and their use of resources for activity" (Pea, 1993, p. 54, italics included). Pea argues that designs are "reliant upon the specific desires in activity" what he calls desire-situation resource pairs. Decades earlier, Vygotsky (1967) used the term desires to describe children's emotional goals in play, arguing that children's learning and development could not be fully understood without attending to the affective and situational circumstances inherent to children's activity (pg. 4). In this chapter, I use the term "desires" in a similar vein to capture the affective dimensions that are ensnared with the nascent goals and motivations that emerge in interaction with other people, physical contexts, and representational tools.

Affect, Aims and Desires in Student Classroom Inquiry

Jaber and Hammer (2016a, 2016b) extend their discussion of affect and aims in science to children's science learning in several classroom studies, focusing on late elementary and middle school students' experiences both in small moments of interaction and a broad sweep across several years. Their classroom studies draw on a larger research project designed to promote and study teachers recognizing, interpreting, and responding to student thinking (*Responsive Teaching in Science*; Coffey, Hammer, Levin, & Grant, 2011; Hammer, Goldberg, & Fargason, 2012). Using micro-interactional analysis methods (Goodwin & Kyratzis, 2007) to study affect emergent in moment-to-moment interactions, in conjunction with a multi-modal approach to identify nonverbal and verbal markers of affect in interaction, Jaber and Hammer trace students' affect emergent in activity. In the first study, Jaber and Hammer (2016b) focus on two different classroom conversations, one involving two 4th grade students discussing clouds and their puzzling ability to hold water and another involving several 5th grade students reasoning about how water expands as it changes from a liquid to solid ice. In both episodes, Jaber and Hammer reveal how feelings of puzzlement, exasperation, enjoyment, and excitement emerge *within* scientific activity of making sense of phenomena and seeking mechanistic explanations of cloud formation and water expansion. In a second study, Jaber and Hammer (2016a) take a multi year longitudinal approach, focusing on one child, Sandra, across four grade levels within the larger research project. In their analysis, they trace how affect, interest, and identity are all intertwined in Sandra's science learning and identification with science across multiple contexts. Through a combination of classroom observations in fourth and fifth grade and interviews in sixth and seventh grade, they document how Sandra's affect and motivation are intertwined in both her in-the moment engagement and her larger experiences of becoming "hooked" on science.

Across both papers, Jaber and Hammer document multiple parallels between students' and scientists' affect and aims within science disciplinary pursuits. They connect their findings with existing accounts of disciplinary engagement in classroom contexts (Engle, R. A., & Conant, 2002; Manz, 2015a; Rosebery, Ogonowski, DiSchino, & Warren, 2010)and scientists' accounts of their disciplinary pursuits (Feynman & Weinberg, 1999; Gruber & Barrett, 1974; Keller, 1984). They argue that this blend of affect and aims is inextricably entangled in the conceptual and epistemological substance of science inquiry (Jaber & Hammer, 2016b, pg. 161), integral to the instigation and stabilization of disciplinary pursuits, and an important aspect of what should be learned in science classrooms.

However, two important questions remain, which I take up in this chapter. First, Jaber and Hammer's moment-to-moment and multi-year analyses provide important insights into affect and aims within short and long durations of time. Yet in order to understand the interplay between affect-laden goals and the science disciplinary practices across longer trajectories of instructional activities, it is also important to explore a middle duration time span within one curriculum. Such a duration allows for an analysis of the interplay of curricular design, affect, and student learning. A second question arises from Jaber and Hammer's close focus on one or two students, specifically about other students' experiences unfolding within the same curriculum. Building on this scholarship, I aim in this chapter to examine how students' desires shape their engagement in a practice-focused curriculum, with attention to shifts over time within this multi-week curriculum. A secondary focus is on the heterogeneity of students' experiences within this curriculum, a perspective not possible with Jaber and Hammer's prior methods because they focus on short interactions with multiple curriculums. In the sections that follow, I describe the context in which I explore these questions, beginning with the curriculum created to study uptake of science practices.

The Development and Implementation of a Practice-focused Curriculum: Life Underfoot in the School Yard

To support children's learning about ecological systems and understand the uptake of science practices in classroom contexts, I developed 10-week curriculum in which students studied the soil ecology underfoot in their schoolyard and engaged in cycles of ecologists' practices, including identifying parts of an ecosystem, transforming parts into measurable variables that they collect, and aggregating, visualizing and discussing their data in partner and whole class discussions. In designing the curriculum, I drew on two sources in the design process, including Science and Technology Studies' depictions of ecologists' practices and design-based research supporting children's reasoning about ecological systems. In this section below, I first describe depictions of ecologists' practices in the Science and Technology Studies literature (Latour, 1999; Pickering, 2010; Hall, Stevens & Torralba, 2002; Bowen & Roth, 2007), including Forsythe's extensive literature review of ecologists' sampling practice from Science and Technology Studies and History and Philosophy of Science literature (Cotterman, 2016: Forsythe 2018). I then describe existing classroom-based research that aims to support elementary students' reasoning about ecological systems and engagement in ecologists' practices (Lehrer & Schauble, 2012; Lehrer, Schuable & Lucas, 2008; Lehrer & Schuable, 2017; Manz, 2015; Manz, 2012; Cotterman, 2016).

The Targeted Ecologists' Practices in the Lessons: Support for System Level Inquiry

Broadly, ecology entails studying the abundance, scarcity and distribution of organisms and the relationships within and between these organisms and their environment (Korfiatis & Tunnicliffe, 2012). Ecologists' practices center around generating and visualizing variation and co-variation within ecological systems, to better understand system-level interactions between living and non-living aspects of the larger system (Cotterman, 2016). Due to the size and complexity of many ecological systems, ecologists engage in sampling select aspects of the environment to understand larger system dynamics (Coe, 2008; Lehrer & Schauble, 2017). Key to sampling is attending to time and space, particularly questions of when to sample and where to sample, to better understand temporal changes and spatial distributions in the system. Ecologists' practices are iterative and cyclical, in that experiences sampling in the field may lead to new questions, and variables and visualizations of co-variation often lead to questions of sampling reliability and methodology (Cotterman, 2016; Bowen & Roth, 2007).

Ecologists' practices can be broken down into three key practices:

Practice 1: Identifying parts of the system. To begin studying the larger ecological systems, ecologists begin by simultaneously defining questions and deciding on what parts of the system are important for answering these questions. Central to such considerations are both living and nonliving aspects of the system, and potential interrelationships among parts. The process of linking questions to defined system elements often is a dynamic and immersive experience, with initial plans shaped by anomalies and variations that emerge in situ in the field. For example, in describing soil and plant scientists, Latour (1999) documented how the question of the savannah advancing or retreating on the Amazon rainforest demanded that the researchers attend to varying parts of the ecosystem as the questions and the variables at play were further refined during early field visits. Similarly, Cotterman (2016) noted several studies where ecologists' initial questions and variables shifted notably in light of material and social pushback (Manz, 2016; Pickering, 2010).

Practice 2: Transforming parts into variables. With questions initially defined and potential parts of the system identified, ecologists begin transforming observations into measurements and other inscriptional forms. These forms often involve increasingly systematic and mathematical notation using varying tools and representational infrastructures (Cotterman, 2016; Hall et al., 2009). In light of the spatial and temporal complexity inherent to field research, data collection protocols and practices are often adapted with frequent attention to *what*, *where,* and *how often* to sample (e.g., Coe, 2008). In regards to *what*, ecologists aim to study not only living organisms but also the broader environmental conditions, and so must balance sampling living and non-living elements to encompass the wider system. In terms of *where*, ecologists often aim to ensure a spatial distribution of sampling sites to provide a more accurate understanding of the entire system. And in regards to *when*, ecologists consider the timing and repetition of sampling, to address seasonal changes as well as potential variability or errors inherent to sampling methodologies. Indeed, attention to time and space in sampling developed gradually in the ecology discipline.

Practice 3: Aggregating, visualizing, and explanation. With initial data collected, ecologists engage in iterative rounds of aggregation and visualizing to examine underlying patterns of variation and co-variation. Multiple data forms are used, often forms that support spatial and temporal displays of interdependent variables such as maps, extensive tables, and computational models. For example, Latour (1999) documented how spatially representing the rain forest-savannah boundary proved essential for scientists in order to understand the explanatory mechanisms of earthworm activity on the rain forests' shifting perimeter. Hall et al. (2002) documented how the representational infrastructure used by entomologists became a crucial and contested site for thinking about termite population and tree species. Moving back and forth, between field experiences and aggregated data, ecologists are able to reason about the system level interactions and potential mechanisms.

Instructional Design

The curriculum was designed to support late elementary students' reasoning about ecological systems, through engaging in recurring cycles of ecologists' practices, which include (a) identifying parts of the systems, (b) transforming parts into variables, and (c) aggregating, visualizing, and sense making of aggregated data and qualitative observations.

Framework "big" questions. As described in the Chapter 2, the curriculum centered around four "big" questions to support children's inquiry into ecological systems and their engagement in science practices (see Table 11). These questions were intended to support problematizing (Philips, Watkins & Hammer, 2018; Dewey, 1929) the physical schoolyard space and considering the different parts' interrelationships, raising questions of methodology and tools, and conjecturing explanations about emergent patterns of covariation in their schoolyard data. These questions functioned as both frames for each lesson's purpose and as a potential bi-directional progression in children's reasoning, from considerations of ***What** is here?* towards ***How** can we find out more?* towards ***Why** might this be?*

Table 11
Framework Questions

Curriculum Framework Questions	**Functions of Questions**
What is underground?	Problematize everyday underground spaces, generate initial parts of system
In what ways are the different parts connected?	Elevate consideration of different parts of system and potential interrelationships among parts of the system
How can we find out more?	Motivate methodology and tool selection, with attention to time (when) and place (where) in sampling activities
Why might this be?	Motivate noting patterns of co-variation among parts and conjecturing potential explanations of these relationships

Social groupings. Dyads were a central unit of activity in the curriculum (Metz, 2011), working relatively autonomously to select sites to study, gather data at their schoolyard sites, record counts and measurements, and work together when the class constructed aggregated data representations. This dyad level activity was balanced in each class with whole class discussions at the start and end of most class sessions as well as frequent opportunities for small group work at tables involving two pairs.

Instructional progression. Across 18 class sessions, students were supported in reasoning about ecological systems through a range of instructional activities. In the text and Table 12, I describe the progression of activities that aimed to support the intended functions of ecologists' practices and children's reasoning about ecological systems.

Table 12

Summary of Instructional Progression, highlighting shifting ecologist's practices

	Ecologists' Practices and Functions of Practices	**Instructional activities to support children's engagement in ecologists' practices to reason about ecological systems**
Cycle I	*Identifying Parts of System* * Define research agenda, including refining questions and potential variables *Begin to differentiate parts of ecological system and consider potential relationships	*Lessons 1-4* *Teacher poses initial questions, of "What is underfoot?" and "How might these parts be connected?" * Students begin to identify and differentiate parts of schoolyard socio-ecological system, voicing different rationales for parts and potential relationships *Teacher sorts initial parts list into living / non-living and above/ below ground lists *Students generate initial list of sites for begin studying parts and potential relationships, visiting potential sites *Students select initial sites for sampling
	Transforming Parts into Variables *Observation and measurement at selected sites to examine variation and co-variation in larger ecological system	*Lessons 5-6* *Teacher leads discussion of potential data collection tools and techniques, posing question of "How can we find out more?" *Students decide on final sites for sampling *Students collect data at sites, including initial site observations outside, soil moisture, soil texture, soil compaction, invertebrate counts (including specifically earthworms), above ground activity and any additional data they think would be helpful for understanding the system, its parts, and interrelationships.
	Aggregating, Visualizing and Explanation * Identify and reason about patterns of co-variation in the ecological system and conjecturing possible explanations	*Lessons 7-12* *Students aggregate all their data using multiple representational formats to begin exploring patterns of variation and covariation in the ecological system (e.g., bar charts, two ways tables, paper and digital maps) * Research Meeting (Lehrer, Schauble & Lucas, 2008) involving students constructing, sharing and contesting patterns in data * Emergent discussions about reliability of methods and resulting data related to temporal and spatial aspects of sampling, sampling area, and variables selected
Cycle II	*Identifying Parts of System* * Refining questions, variables and methodologies in response to earlier findings *Further differentiate parts of ecological system and consider potential relationship	*Lesson 13* *Teacher leads discussion of potential data collection tools and techniques, posing question of "How can we find out more?" * Students plan and select second site, with student pairs deciding between returning to the original site or selecting a new site
	Transforming Parts into Variables *Observation and measurement at selected sites with select variables to examine variation and co-variation in larger ecological system	*Lessons 14-15* *Student collect data at original site or new site, including soil moisture, soil texture, soil compaction, invertebrate counts (including specifically earthworms) and above ground activity
	Aggregating, Visualizing and Explanation * Identify and reason about patterns of co-variation in the ecological system and conjecturing possible explanations	*Lessons 16-18* *Students aggregate data at whole class level, generating bar charts and interactive GIS maps to examine variation and co-variation to reason about underlying mechanisms * Research Meeting (Lehrer, Schuable & Lucas, 2008) involving constructing, sharing and contesting patterns in data as well as revising research questions and methods

Methods

Selection of focal pairs. From the three focal pairs (n=6) studied in this project, I selected two focal pairs, Lena and Max and Amir and Marie for closer study. I selected these two pairs because they represented a notable contrast in experiences, in terms of how they went about selecting their two sampling sites, their choices out in the schoolyard gathering data, and their participation in data representational activities.

Data collection. Over the course of the 18-lesson curriculum, several data sources were collected that I detail below.

(a) Video and audio recordings. During each class session, I collected multiple video recordings, capturing interactions at the whole class, small group, and dyad level interactions. For whole class activity, I used two cameras in each class session, including a classroom wide-angle camera capturing whole class activity and a focused-angle camera documenting discussions in the rug area. During small group table activities, I video recorded the focal student pairs. During lessons that took the class outside the classroom, general activity was recorded using a wide-angle camera, focusing at times on the focal dyads activities. Lastly, I also wore a GoPro mobile camera during most class sessions, enabling me to capture my informal interactions with students and also add an additional perspective to the video record.

(b) Student and teaching artifacts. Student and teaching artifacts were also collected. These included students' written work, such as site selection rationale sheets, data collection note sheets, and general note sheets and teacher/ student generated data forms, such as bar charts, two way table of invertebrate data, paper and digital data maps showing sites and related data. (See Appendix B for focal students' artifacts, including site selections rationale sheets, and data collection field notes and Chapter 5 for teacher/ student generated forms).

(c) Semi-structured interviews. At four points in the curriculum, I conducted semi-structured interviews with focal students individually. During these interviews, ranging from 20-40 minutes, I asked questions about the child's experiences and decisions engaging in the three ecologists' practices, such as students' rationale for particular sites selected, their experiences collecting data in the schoolyard, and activities related to collective construction of varied data representations (bar chart, two way table, interactive digital maps). In the last interview, I asked additional questions about students' reflections engaging in (See Appendix X for semi-structured interview protocols).

Analysis. To analyze children's desires and their engagement in science practices to support reasoning about ecological systems, I organized my inquiry into two phases.

Phase one. In the first phase, I organized the extensive data corpus into the three main ecologist's practices: (a) identifying parts of system (L1-L4 and L13), (b) transforming parts into variables (L5-L7, L14-L15), and (c) aggregating and visualizing (L8-L12, L16-L18). Within each group of practices, I identified relevant whole class and dyad video, student and teaching artifacts and semi-structured interview involving the two student pairs (see Table 13, showing relevant data sources for each of the three ecologists' practice).

Table 13

Analysis Phase One: Practices and Data Sources

Practices and Lessons	Instructional Activity	Data Sources
Identifying Parts of the System (L1-4)	Discussing potential parts of the system Discussing and deciding on the first sampling site	Whole class video (including outside) (L1-L4) Dyad video Teaching Artifacts: Parts of System Brainstorming List, and Initial Site Selection Map Student Artifacts: Site Planning/ Selection Sheets #1 Semi-Structured Interview #1 (post L4)
Transforming Parts into Variables (L5+6)	Collecting data in pairs throughout the schoolyard	Whole class video (including outside) (L5-6) Dyad video (L5-L6) Student Artifacts: Data Collection Field Notes #1
Aggregation, Visualization and Discussion (L7-L12)	Collectively aggregating and discussing data into multiple data forms:	Whole class video (L7-L12_ Dyad video (L7, L10) Teaching Artifacts: Collectively constructed bar charts, two way tables, sticker data maps, and interactive GIS data maps Semi-structured Interview #2 (post L9)
Identifying Parts of the System (L12-13)	Discussing potential parts of the system Discussing and deciding on the second sampling site	Whole Class Video (L12-L13) Dyad video (L13) Student Artifacts: Site Planning/ Selection Sheets #2
Transforming Parts into Variables (L14-L15)	Collecting data in pairs throughout the schoolyard	Whole class video (outside) Dyad video Teaching Artifacts: Second Site Selection Map Student Artifacts: Data Collection Field Notes #2
Aggregation, Visualization and Discussion (L16-L18)	Collecting aggregating and discussing data using interactive data maps:	Whole Class Video (L15-L18) Dyad Video (L15) Student Artifacts: Presentation Planning Notes + Research Meeting Notes Semi-structured Interview #3 (post L17)
Post Instruction		Semi-structured Interview #4

Phase two. In the second phase, I focused in on the two pairs' experiences across the multiple data sources and practices, with attention to students' emergent desires. I began by reviewing existing video logs of whole class and dyad video, with a focus on the focal pairs' activity as they suggested initial parts of the system, considered different sampling sites, collected data at their selected sites, and aggregated data into varied representational forms to explore patterns of co-variation. I reviewed the four semi-structured interviews with the selected focal students as well, focusing on the student pairs' responses to questions about their experiences across the three practices. Within these interviews, I used video-coding software to mark students' specific reference to and reflection on engaging in specific practices as well as students' desires evidenced in both verbal and non-verbal clues. Video analysis enabled exploring how children's desires emerged in classroom interactions in relation to varied social grouping and representational tools (Derry et al., 2010; Goodwin & Kyratzis, 2007). As Jaber and Hammer (2016b, pg. 168) noted, video analysis also supported a multi-modal approach (Stivers & Sidnell, 2005) to studying affect-laden desires emergent in activity, including body postures and movement, facial expressions, and temporal coordination of gesture and talk.

In addition to these video data sources, I also reviewed student and teaching artifacts created during these whole class and dyad level activity, examining students' written rationale for site selection and their field notes to see what parts of the systems they were attending to at various points and what rationale they offered for site selection. By coordinating these different data sources, I was able to triangulate (Yin, 2014) my observations and analysis, yielding a fuller picture of the pairs' activities and their desires within and across practices.

Longitudinal Analysis of Four Students' Engagement with Ecologists' Practices

In this section, I examine how children's desires brought them into closer alignment with ecologists' sampling and representational practices, creating confluence, as well as when their desires clashed with those practices. In each subsection of practices, I begin by briefly describing the instructional activities that aimed to support children's engagement in ecologist's practices and reasoning about system-level interactions. I then examine each pairs' experiences within this practice, revealing how children's desires both aligned and clashed with ecologists' practices and how these clashes and confluences opened up or closed down different learning opportunities.

Section I: Engaging in Practices of Identifying Parts of the System and Transforming Parts into Variables

Summary of ecologists' practices and lesson activities. To support children's study of their schoolyard soil ecological system, early lessons in the sequence focused on two key practices: identifying parts of the system and transforming these parts into variables through sampling. The purpose of centering these practices at this point was to define research questions, identify relevant parts of the system, and collect select data in the field to support understanding of system level interactions. Key ideas central to these practices are (a) attending to both living and non-living parts of the environment, in particular potential interactions among parts, and (b) attending to time and space in sampling decisions, to ensure spatial distribution of sampling sites that better reflect the larger system functioning, as well as repeating sampling at the same site to address potential changes over time in the system.

During these earlier lessons (Lessons 1-4), students discussed potential "parts" of the schoolyard soil ecology, with the teaching splitting these into biotic and abiotic categories (see image x in methods). As pairs, students visited different schoolyard spaces and selected an initial site for sampling to study interactions between the living and non-living parts in greater detail.

At their sites, students collected a range of data about earthworms, other invertebrates, and plants' root structures, as well as soil characteristics such as moisture, compaction, and composition. After several class sessions devoted to exploring relationships in the aggregated data, students had the opportunity to select a second sampling site in Lesson 13 to further support studying relationships emerging in the class data, as well as puzzling patterns, outliers, or anomalies in the data.

Pair 1: Amir and Marie (clash into confluence). Amir and Marie's emergent desires to find lots of animals and be in a special schoolyard place gradually supported confluence with ecologists' practices, such as attending to multiple living and nonliving parts of the system, attending to potential changes in the system due to weather and time passing and considering repeating sampling at their original site to address potential errors.

Initial site selection and data collection. In the initial lessons focusing on transforming parts into variables, Amir and Marie were excited to find lots of animals and be in a favorite schoolyard space (dyad video, L1, L2; site planning sheets L1, L3). In selecting their initial site, they decided on a site in the pond area, a tucked-away spot likely to yield lots of animals and known from their earlier years playing during recess in the schoolyard. In the first interview (Interview #1), Amir and Marie shared their site choice and rationale, animatedly explaining their focus on findings lots of animals. Amir began: "I really like to study the animals! So I wanted to be in the pond [area]… I thought the soil was really healthy so more animals would like to go there to find food to eat. And also, there's a lot of water. And also, there are a lot of plants there and sometimes berries." Amir continued, describing all the animals he and his partner were likely to see near their site, such as "woodpeckers, a lot of caterpillars, and worms - lot of worms! and even pregnant worms too!!" Marie offered a similar rationale, saying: "We wanted to pick a place where nobody would step on it and where the soil was the wettest because we really wanted to find some worms." In addition, she described the site as a place she knew well from her earlier years at the school, a "lovely, hidden spot!"

For Amir and Marie, their initial site selection was shaped by their shared desires to find lots of animals, in turn supporting their consideration of numerous living and non-living parts of the system that might ensure unearthing earthworms. Their desire supported their consideration of how various plant and animal species might be influenced by the sites' soil moisture and foot traffic. Lehrer and Schauble (2015) have noted students' initial attention to animals as a generative basis for beginning to think about ecological systems, documenting how initial focus on particular organisms gradually shifts to thinking about specific organisms' needs getting met in particular niches, a key shift in reasoning about ecological systems. For Amir and Marie, it appears that their desires supported their attention to both animals and abiotic characteristics of the schoolyard environment.

Second site selection and data collection. When it came time to transform parts into variables a second time with another site selection, Amir and Marie's desires continued to bring them into alignment with ecologists' practices, resulting in the pair returning to sample a second time at their site. They explained their choice as addressing potential changes due to time passing and weather patterns as well as to address potential errors in their sampling methodology. Notably, they were one of only two pairs to return to their site a second time, compared to the classes' eleven other pairs that sampled in new locations. In their planning notes, the interviews and whole class discussions, Amir and Marie described their desires to continue finding lots of animals, to be in a space they loved, and to see how the site and the larger system might change due to time passing and recent weather patterns as well as errors in sampling. In their Lesson 13 planning sheet, Marie and Amir wrote they were selecting their site a second time "because therir [sic] are lots of animals and we would like to see what more we could find. And if the season/ day/ month changes we will see the differences?" This last rationale is notable, in that a key aspect of thinking about ecological systems involves thinking about parts, relationships among parts, and changes in these relationships across time and space (Cotterman, 2016; Lehrer & Schauble, 2017).

Marie's desires surfaced again during a whole class discussion where students shared their rationales for choosing their second sampling site locations. At Marie's turn, she came up to the large map and pointed to their second site, excitedly explaining that her and Amir wanted to see "if it changes due to the recent rainfall and time passing, especially how the animals handled it all". Yet as she walked back to her rug spot, she revealed her desire again, adding "and… also, because we love it [their site!] (*grinning and throwing her hands up*)." Marie's desires to be in a favorite schoolyard spot that she "loves" was intertwined with desires to see how animals are influenced by changing weather and time passing. A strong connection to animals and place among professional scientists is also evidenced in Science and Technology Studies literature, where ecologists' practices are instigated and stabilized by deep connections to organisms and their surrounding environments (e.g., Bowen & Roth, 2007; Keller, 1983).

Marie and Amir's desires influenced not only their actions in selecting sampling locations and collecting data in the schoolyard, but also their thinking about purposes of ecologists' sampling procedures. In the last interview (L #4), Amir and Marie were asked about the value of sampling more than once, an important practice in ecology to address variability in data due tool performance and seasonal shifts. In response to the question, both Amir and Marie said it would be important to sample repeatedly, "to see if things changed, like the animals, the soil, the area" and also to see if they had made sampling errors. This attention to change and error are key aspects of ecologists' sampling activities, as they engage in the practice of transforming parts into variables.

Summary. Evidenced in their planning notes, interviews, and whole class discussions, Amir and Marie's desires to find animals and be in a favorite schoolyard spot that Marie "just loves!," became intertwined with the pairs' attention to multiple living and non-living parts of the soil ecology system and potential changes in the system related to time and weather. Moving from the first site selection to the second site selection, Amir and Marie's desires supported closer alignment with the ecologists' practice of repeat sampling, attending to changes over time, and addressing inherent errors and variability in the data. As they moved from planning sites to actual data collection across the two inquiry cycles, Amir and Marie's desire-laden focus on animals gradually opened up several key insights. These included coordinating multiple parts of the environments and increasingly attending to seasonal and temporal change at their site and potential errors in their data.

Pair 2: Lena and Max (confluence and clash). Lena and Max's desires led to a notably different engagement with the ecologists' practices supported in the curriculum, leading to both clash and confluence as they engaged in the changing practices. Despite an initial alignment with the ecologists' practice of selecting spatially distributed sites to explore relationships between biotic and abiotic variables, Lena and Max switched twice, in the midst of data collection, to sites that were in close proximity to Lena's friends and likely to yield high earthworm counts.

Initial site selection and data collection. Lena and Max began in close alignment with many ecologists' practices, in particular focusing on studying relationships among animals and environment in spatially distributed sites. In Lena and Max's site selection discussions and written notes, they decided on a relatively undisturbed area, a hidden spot along schoolyard perimeter fence that they had both noted was a relatively isolated space in the schoolyard (dyad video, L1, L2; site planning sheets L1, L3). In the first interview (Interview #1) and their site selection note sheets, Lena and Max explained their rationale for this site choice. Max wrote that he wanted to study the "sidelines because I want to see how the living and non-living things cope with the concrete" (Max note sheet, L3). Lena's written rationale was similar. This focus on studying living and non living parts of a system and their potential interrelationships is a key practice for ecologists, shaping both initial questions as well as field-based sampling activities.

Lena's desires for discovery and novelty also led her to argue for ensuring a spatial distribution of sampling sites. In L 3, the teacher posed the question "Why might we not want to sample all in the same spot?" Several students shared their ideas, mostly evoking practical concerns related to safety and damaging the sampling sites. Yet when Lena raised her hand to share, she argued that students should be sure to spread out for a notably different reason. Lena added: "Well, kids would be finding out the same [dragging out word] information so everyone would be figuring out the same stuff about one small spot and it would be kind of *boring* [dragging out word]… nobody is finding out new information" (L4_whole class video, @9:30.) In framing her rationale this way, Lena reasoned that by spreading out sites, not clumping all together, that kids could learn more about the whole area and it would make for a more interesting experience. This is an important idea in ecologists' sampling activity, in that spatially distributed sites offer a more accurate understanding of the whole system (Lehrer & Schauble, 2017). Here, Lena's desires for novel and interesting findings appear to help her consider this important point. In the first interview, Lena reiterated the value of spreading out sampling sites and also talked about her intertwined interest in discovering the "unknown," finding unique animals, and seeing relationships for herself. In these moments, it appears Lena's desires for "discovery" and "novelty" were as much a part of her actions to spread out sampling locations compared with her peers.

However, on Lesson 5 the next day, Lena and Max chose to switch locations. That day, as Lena and Max began digging at their original site, relatively isolated along the schoolyard perimeter, shrieks of excitement could be overheard in the school garden about 50 yards away (outside video_L5). There, several other student pairs were sampling at sites and uncovering relatively large amounts of invertebrates in the soil. As Lena and Max continued at their initial site, they found no signs of animals. After about five minutes at the site, Lena and Max gathered their tools and note sheets and relocated to the garden's compost pile, teeming with earthworms and within arms' reach of Lena's friends and their sampling sites.

In reflecting on their experiences on site planning and selection, Lena and Max acknowledged how their shifting desires shaping their site selection and data collection activity. In the last interview (Interview #4), Lena remarked, "My partner wanted to go somewhere where there is dry soil and less animals and I wanted to go where there were a lot of animals… I mean, the soil layers we found were cool and all but …. " Max shared similar sentiments, saying "I think Lena was really excited about finding lots of earthworms." Max also added that site selection ultimately depended on kids' aims, saying: "It depends on your goals. If you want to find worms, you go to the garden! How could it be a garden without worms!" For the pair, it appears Lena's desires to find earthworms shifted the pair away from thinking about the wider ecological system and studying relationships among biotic and abiotic variables.

Second site selection and data collection. At the start of the second inquiry cycle in Lesson 13 when pairs had the opportunity to select a second sampling site (either their original site or a new site), Lena and Max again moved farther away from ecologists' practices. As they sat at their classroom table planning, they both recorded their original site in the Kindergarten playground area, with Max explaining his rationale to study "the balance of living and non living parts." But Lena seemed notably upset by this choice, with her arms folded across her chest and sitting back in her chair for much of the site planning discussion. In her note sheet rationale for site selection, Lena wrote only "ask Max" (L13 note sheet, Lena). Yet as the class headed out to gather data at their site the next day, Lena and Max again switched to a different site, a site near the playing fields likely to yield more earthworms. In their revised note sheets and later interviews, Lena described the newly selected site as an opportunity to test her conjecture that earthworms would prefer lots of decaying plants. In reflecting on the site selection and data collection activities (Interview #3), Lena said, "Like when *I* was picking my own site, it was just all about more, more, more [banging table for emphasis]", referring to finding more animals (Interview #4, 27:50). Max noted simply, "Lena wanted to go to *that* new site with worms" and explained that he had wanted their first site along the Kindergarten wall all along.

Lena and Max's desires influenced not only their actions in selecting sampling locations an collecting data in the schoolyard, but also their thinking about purposes of ecologists' sampling procedures. In the last interview (L #4), Lena and Max were asked about the value of sampling more than once, an important practice in ecology to address variability in data due to sampling techniques and seasonal shifts. In response to the question, both Lena and Max said it would be important to sample repeatedly. Notably, however, both gave turn-taking purposes as the reason for repeat sampling, rather than addressing potential variability in data samples or sampling errors. For Lena and Max, the social negotiations inherent to coordinating their shifting and varied desires between the two of them markedly shaped their understanding of a key ecological practice, repeat sampling. In light of these experiences, the pair suggested that a teacher decide sampling sites, not letting children choose.

Summary. As they moved from planning potential sites to gathering data at their actual schoolyard sites, Lena and Max's desires aligned and then clashed with ecologists' practices of identifying parts of the system and transforming parts into variables, influencing their sampling site locations and considerations of system level interactions. In contrast to their early site location and rationale focused on spatial distribution in the school yard and studying interactions, they switched to sites close to friends and likely to generate lots of earthworms. Additionally, the pair considered repeat sampling useful for turn-taking reasons, missing the intended purposes of repeated sampling practices to address variability in data due to error and seasonal variability.

Section II: Practices of Aggregating, Visualizing and Discussing

In this section, I describe the two pairs' experiences engaging in practices of aggregating data, visualizing distributions and co-variation among variables, and discussing patterns in the data. I focus on children's emergent desires in these representational activities, shaping both alignment and clashes with the intended purposes of ecologists' practices.

Summary of ecologists' practices and lesson activities. To support children's study of their schoolyard soil ecological system, these class sessions focused on the ecologists' practice of aggregating, visualizing and discussing. The purpose of this practice is to (a) visualize patterns of variation and co-variation among variables, with an eye on understanding potential mechanisms underlying patterns of abundance and distribution in the larger ecological system. Key ideas are accurately reporting data and using a variety of data forms to examine distribution and co-variation across multiple variables to understand the larger system level interactions at work.

After collecting data in the schoolyard, several lessons (L8-L12, L15-L18) were devoted to exploring the classes' data using a variety of data forms (tables, bar charts, two way tables, paper data maps, digital data maps). Working as a whole class, pairs collectively constructed all these data forms, bringing forth their data from their note sheets and their experiences gathering the data at their sites to created varied representational artifacts. I focus on two different class sessions in the first cycle, involving students in the collective creation of a two-way table of invertebrate data and bar chart of soil moisture, earthworm, and general site locations. I selected these two representational forms and lessons because the focal pairs were active contributors to the collaborative construction process and discussions that ensued. Additionally, the pairs' desires markedly shaped different experiences and reflections on the purpose of the representational forms in the interviews.

Pair 1: Amir and Marie (confluence). As Amir and Marie engaged in this collective construction of a two-way table (see Figure 21), their desires to show up accurately in the data led them to present uncertain data, even though it was difficult to accurately identify the invertebrate species they had unearthed. This desire to show up aligned with ecologists' practices of accurately and thoroughly reporting data when aggregating, visualizing and discussing data.

	OTHER INVERTEBRATES					OTHER INVERTEBRATES								
EARTHWORMS	EARWIG	ANT	GNATS MYSTERY FLY	?	? FARS+KATHA ?	ROLLYPOLLY	OTHER FLY?	BEETLE	SNAIL	SLUGS	MILLIPEDE ~~CENTEP~~	CENTIPEDES	SPIDER	EGGS
21	1							2						4
7				nest of animal inside tree							2			
15½	2								1			1		3
6	1										1	~~1~~		
3						1				1	2		2	
8			1					1		4				
6	1												1	
3							1							
		20	31	60										
6 worms										1 Poop thing				
		1				1							1	
			1											
1							1				1			

Figure 21. Student-constructed two-way table of invertebrate species data. Yellow post-it notes reflecting different counts at pairs' sites, with different species listed across the top of the table and students pairs' site listed along the tables left side. Student names and site locations cropped from left side to make artifact anonymous.

Building and discussing a two-way table. In this class (Lesson 9), students constructed a large two-way table of all their invertebrate counts. The objective was to support students' attention to the abundance and distribution of organisms; in particular to visualize the wide range of different invertebrate species unearthed and the different counts for each species. To assemble the invertebrate species list across the top row of the chart, the teacher asked students to return to their field note data collection sheets and to call out all the different animal species they found sampling at their site. Several children shared different species, such as earwigs, ants, and gnats. When Amir, who had been waving his hand the whole time, is called on, he animatedly describe what he and Marie found (L9, whole class video, 13.12): "We found this white, like flat rollie pollie but like, um every time you poke it in the center, it just unraveled itself and pops!" Teacher 1 remarks: "This was a fascinating animal … that for now I am just going to call Amir and Marie's mystery animal (writing "mystery animal" in the column heading)". Later, once the two-way table was populated with everyone's data, the class was invited to share observations about their invertebrate data, noting the presence and absence of data as well as emerging relationships among the data. Amir raises his hand, clarifying what is recorded on the two-way table.

> Amir: In ours, it says mystery but we actually found a nest too!
>
> Myisha: Ya'll find the weirdest things!
>
> Bea: So if Amir and Marie found a mystery bug, why do we need to write it?
>
> Marie and Amir, talking in overlapping speech: "Well, because we didn't know (emphasis) what it was. That's why it's called mystery bug!"
>
> Kathryn: "They weren't sure. This is a challenge scientist have a lot. They sometimes find animals they aren't sure of, hard to classify (pointing to the bar chart and Amir and Marie's data). I think they are holding there (pointing to bar chart) this interesting animal that they found. Let's hear from Amir and Marie a little more about it because it's good to put something even if you are not sure."
>
> Marie: We found a nest of these weird bugs! Near the tree.
>
> Amir: A nest! Like a firecracker! 'cause they pop! (opening his hands quickly)

From their engagement in this activity, it appears that Marie and Amir's desires to have their findings accurately reported even if they didn't have the know the right species classification aligns with ecologists' practices of attempting to accurately account for all data. It also appears that the mystery and puzzlement of this organism was compelling for the pair, evidenced in their animated talk and their actions of bringing forward this hard-to-categorize species.

Amir and Marie's desires influenced not only their actions in reporting their mysterious data, but also their thinking about purposes of ecologists' representational activity. In the last interview (Interview #4, 6:20) when the children were asked about the different representational forms and which they'd recommend to other classes, Marie recommended the two-way table, saying "I like how you can see *all* the different animals, including how many animals and how many different kinds." Amir made similar comments in his interview, saying "I like the big post it chart 'cause you could see all the data, where there was lots of somethin' and where there wasn't any." For Amir and Marie, it appears that they appreciate being able to see the distribution of invertebrate data, the main purpose behind ecologists' aggregation and visualizing activities. For Amir in particular, his attention to presence and absence is also in close alignment with ecologists'' representational practices, where sampling that yield something can be just as telling about an ecological system as sampling that captures "nothing". As Lehrer & Schauble (2017) and Cotterman (2016) both note, this is a challenging idea for children, coming to record and see the value in "nothing" in data representations.

Pair 2: Lena and Max (clash). In contrast, as Lena and Max began collectively aggregating and representing their data across multiple formats, their desires pushed them further from key ecologists' practices. Lena and Max's desires shaped not only how they went about reporting their data in the class bar chart (e.g., falsely elevating their earthworm counts to have the highest counts) but also their thinking about the possible utility of representational forms themselves (e.g., utility of the bar chart form). (See class constructed bar chart in Figure 22).

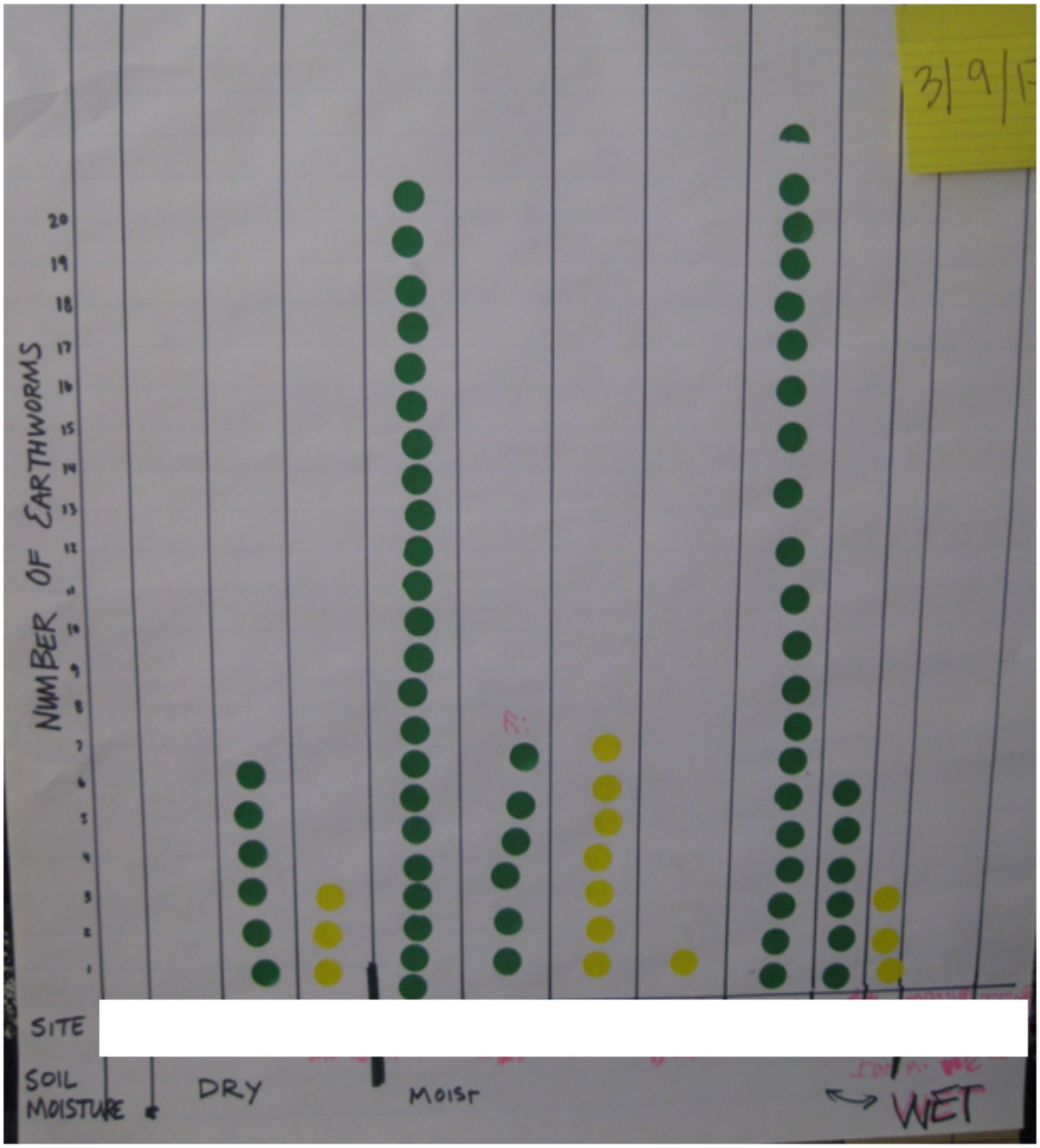


Figure 22. Earthworm, Soil Moisture and Site Location Bar Chart. Earthworm counts are depicted as sticker dots, where green stickers reflect garden sampling locations and yellow stickers show pond sampling locations. Along the bottom horizontal axis, the students' sites are grouped according to the soil moisture (dry/ moist/ wet). For example, on the left horizontal axis, there are three groups who had dry soil, with one group finding no earthworms, a garden location finding six worms and a pond site finding three earthworms. Note Lena and Max's 21 ½ earthworm count on the right side of the bar chart.

Assembling the earthworm bar chart. In this class session, student pairs took turns coming up to the large chart paper and adding their earthworm counts. The purpose of this activity was to explore both the distribution of the earthworm counts and potential co-variation in earthworm counts, in relation to soil moisture and spatial location. Despite having recorded 15 and 15½ earthworms on their data collection note sheets (L5/6 field note sheets), as Lena and Max moved up in the line, Lena can be overhead advocating for elevating their earthworm count to 21½, making it the highest count in the class. She argues that they should collapse their other invertebrate counts from the pitfall trap cup method into their total earthworm count.

> Lena: We had 21, including the ones in the cup [referring to the pitfall trap cup.] Let's count it as 21.
>
> Max: No, we had added those (looking quizzically at Lena).
>
> Lena: No! It was 15 ½ and so … lets just say 16 and then I found other cups, remember .. other worms in that cup, so it is 21.
>
> Max: So it is 21½? (raising his voice in questioning).
>
> Max (turning to the teacher): Can we have like three of them [sticker sheets] but (turning back to Lena) we like already recorded it as 15! (referring to their field note sheets)
>
> Lena: No it is okay. It is 21, 21½ … No, it doesn't even go up to 21 [pointing to bar chart ending at 20] so we'll just go to 20.

As Lena and Max finally make their way up to the chart, they begin adding stickers to show their earthworm counts. They stack 21 stickers total, tearing one extra sticker dot in half to make the remaining ½, making their column the highest in the class. As several groups begin to move away from the bar chart, having completed adding their earthworm counts, the chart becomes more visible to the whole class spread out on the rug. In this moment, as the fully constructed bar chart comes into view, Lena excitedly announces and gestures across her earthworm count of 21½. In light of questions made by one student, Lena and Max restate their elevated count, noting that their precision of ½ is important.

> Teacher 2: "Whoa! You guys! Look the bar chart"
>
> Ellis: "I know, in ten minutes, it has grown like tens!"
>
> Teacher 2: " I know!!
>
> Multiple kids: Oh my gosh, other exclamations heard.
>
> Lena: 21½! … 21½! [with increased emphasis, bringing her hand up and down across the chart and her column of stickers as she says this.]
>
> Jeff comes up towards the chart, "WAIT, is this like also invertebrates too?
>
> Teachers 1: "Well, let's take a look, let's take a look."
>
> Another child calls out from the background: "No Jeff, it isn't other invertebrates. It is just earthworms!"
>
> Jeff turns to Lena, "Then why is that 21?," gesturing towards the bar chart

Lena: It is 21½, we found half a worm!

Jeff: You found 21 worms [elevating voice in disbelief]?

Lena: 21½!

Max (smiling): The fraction is important!

In this moment, Lena triumphantly announces and gestures across her earthworm count of 21½ earthworms. In light of questions made by Jeff, Lena and Max restate their count, noting that their precision of ½ is important. Here, it appears that the class activity of visualizing variation in earthworm counts in the bar chart is interpreted by Lena and later Max, as a competitive endeavor, with having the most being more important than accurately reporting their findings.

Lena and Max's desires to win what they perceived as a competition influenced not only their actions in constructing collective data forms, but also their thinking about the utility and purpose of the representational forms for studying ecological systems. In the final interview, they were asked about the different visual forms we used, how useful they were for exploring variability in the data, and if they would recommend them to be used with future classes. Lena and Max had markedly different responses to these questions. Lena said she would not recommend the bar chart, describing the construction process as a competitive activity. She added (Interview #4, at 27;00): "I thought of it like a competition, weirdly enough and so I was like… 'I need to go to places that are thriving' and now I am like, Why did I do that now?... So I didn't think [the bar chart] wasn't too helpful because I have a problem with that …."Yet Lena also shared that all these feelings and aims also important, adding "but you don't want to be a zombie…. you need to feel this stuff!" In contrast, Max argued that he liked how "you could see the spread of everyone's data" with the bar chart but thought a "massive" two-way table with lots of different variables would be best for seeing relationships across all the variables. Here, Max appears to appreciate the two representational forms utility in making visible both distributions and co-variation among variables, aligning more closely with the intended purpose of the representational activity.

Discussion

In this chapter, I examined how students' desires were intertwined in their engagement in the ecologists' practices supported in the curriculum. Through longitudinal analyses of two 5th grade student pairs, I find children's desires sometimes aligned with the purposes of ecologists' sampling and representational practices and sometimes created clashes with those practices. These clashes and confluence in turn opened up different learning pathways for reasoning about complex ecological systems. For Amir and Marie, their delight in finding animals and being in a favorite schoolyard locale opened up considering the utility of repeat sampling, to attend to temporal and seasonal changes in an ecological system and to address potential errors in sampling. Additionally, their desire for their "mystery animals" being accurately accounted for led to careful reporting of data, even for hard to categorize species. In contrast, Lena and Max's desires led in more of a zigzagging motion, with the pairs' desires initially aligning with ecologists' sampling practices attending to spatial distributions of sampling sites as means for ensuring a more accurate depiction of the larger ecological system and approaching sampling as an opportunity to study relationships among biotic and abiotic variables. But out in the schoolyard, the pairs shifted two times to sites within arms' reach of friends and likely to yield high earthworm counts. Further, Lena and Max's desires to have the highest earthworm counts in a class bar chart lead the pair to falsely elevate their data, a clash with the purpose of ecologists' representational activity aimed at accurately highlighting distributions and co-variation patterns. As such, children's desires were not only integral to their engagement in science practices but also consequential for learning about sampling and representational activities central to ecologists' pursuits.

Parallels are evident in contemporary STEM educational research and Science and Technology Studies, where a wide range of affect-laden aims serves to instigate, stabilize, and destabilize disciplinary endeavors. In Jaber & Hammer's two studies as well as related work focusing on students' STEM disciplinary engagement, frustration, joy, competition, and puzzlement are all interwoven in posing new questions, critiquing claims, and reasoning about complex data (Engle, Langer-Osuna, & McKinney de Royston, 2014; Jaber & Hammer, 2016b, 2016a; Manz, 2015a). Scientists' memoirs, ethnographies', and autobiographies revel similar varied experiences, such as embodying and empathizing with organism of study to better understand underlying mechanisms (e.g., Keller, 1984; Ochs, Gonzales & Jacoby, 1996) and fear of critique and competition integral to discoveries and innovations (e.g., Thagard (2008) describing Watson and Crick). Across these sources, desires appear intertwined in scientists and students' pursuits, motivating and sustaining science practices.

Building on Jaber & Hammer's work (20016a, 2016b), my methodological approach offers useful insights into the larger question of *how* science practices are taken up in K-12 classrooms by following and contrasting two pairs' desires and experiences within one curriculum. By studying two focal pairs, it was possible to illuminate the dynamic nature of desires emergent in activity, both unfolding within the pair itself and across pairs. This analysis also provides a glimpse into the heterogeneity of desires likely playing out simultaneously in classroom communities, an important element of learning contexts (Rosebery, Ogonowski, DiSchino, et al., 2010). By extending the analysis across several practices within one curriculum, I was able to examine how desires can shift and change in light of particular design elements such a student choice in selecting site and collective constructions of class aggregate data using different representational forms. This mid-level approach supports considerations of how desires, instructional design choices, and learning over time are interwoven. For example, for Lena and Max, we saw markedly different desires emerge in planning potential sites compared to collecting data out in the schoolyard or publicly displaying findings in a whole class setting. In contrast, Amir and Marie's desires for discovering and talking about many different animals remained more steadfast across practices.

From this initial work, two key implications come forth related to classroom practice and future lines of research.

Desires to be expected and supported. Jaber and Hammer argue that engagement in science practices inherently involves learning at the level of affect – that a key part of what is to be learned in science classes is experiencing and navigating varied feelings and motivations emergent in inquiry pursuits (Jaber & Hammer, 2016, p. 195). Findings in this study bolster this argument, with both pairs' desires central to their science inquiry. Yet these experiences of delight, fear, excitement, and competition may be unfamiliar to students in science classroom contexts. Additionally, for younger learners in particular, coming to navigate varied desires for themselves, within pair interactions, and within whole class contexts can be a challenging undertaking. For practitioners and researchers, it will be crucial to not only expect but support children in wrestling with a wide range of feelings and motivations as science instruction comes to more closely resemble the social knowledge-building practices of scientists.

Desires intertwined in design. Yet as Pea (1993) notes, desires are inextricably bound to the contexts in which they emerge, with "design reliant upon the specific desires in activity" (Pea, 1993, p. 56). Indeed, Pea argues that learners' novel and inventive interpretations of these "desire-situation resource pairings" lay at the heart of learning processes. Recent design-research in science education has focused on curricular designs that engage students in the challenge and delight of structuring the ill-structured (Metz, 2011) intentionally designing for students to engage in the complexity and messiness of science inquiry (Manz, 2016; Philips, Watkins & Hammer, 2018). Such design work might benefit from further articulations of how affect and aims are supported and emerge in classroom-based research, complementing details accounts of material and social design choices. I see this analysis as an embedded case study illuminating such interactions.

In light of the "practice turn" (Ford, 2015) evident in the *Next Generation Science Standards* and the National Research Councils *K-12 Science Framework* (NGSS Lead States, 2013; NRC, 2011), there is increasing interest in understanding *how* science practices come to be needed and adapted in classroom contexts, in ways that simultaneously honor children's perspectives and the intended functions science practices serve in scientists' pursuits. I argue an expanded conceptualization of science practice, one that encompasses learners' affect and aims, in coordination with careful attention to the design of learning environments, is a crucial step. Through "thicker" accounts (Ryle, 1971) of classroom activity that attend to social, affective, and material dimensions, researchers and teachers will be posed to not only better support knowledge-building practices of sciences in classroom contexts but also acknowledge and affirm children's affective and agentive experiences inherent to learning science.

Chapter 6
Discussion and Future Research

In my dissertation, I examine the potential of place-based inquiry together with digital GIS mapping tools to support late elementary students' science learning. I focus on how students' may leverage their everyday experiences and perspectives as they engage in both science disciplinary practices and reasoning about ecological systems. In this final chapter, I elevate key findings from this research study. I then consider implications for both theory and the design of science learning environments. I conclude by discussing limitations of the present study and promising directions for future research.

Major Findings

My major findings center around three areas - science disciplinary practices, place-based science, and participatory GIS mapping. Each of these areas relates to key problems in science education. These problems are outlined in the Introduction and reflected in my design principles outlined in Chapter 2. The findings are:

Desires shape students' engagement in science disciplinary practices. Consensus documents in science education policy (NRC, 2012; NGSS, 2013) call for engaging K-12 students in the practices of scientists. This shift toward science disciplinary practices - what Ford (2012) calls the "practice turn" - aims to better reflect the social, material, conceptual, and epistemic knowledge-building activities of scientists within the classroom context. Yet as Manz (2016) argues, a key question for educators and researchers alike is how to design classroom contexts that foster a *need* for science disciplinary practices.

Recent work by Jaber and Hammer (2016a, 2016b) suggest that scientists and students' affect and aims are integral to how science disciplinary practices are instigated and stabilized. Drawing on science and technology studies literature and empirical classroom-based research, Jaber and Hammer argue that scientists and students' affect and aims are inseparable from the conceptual and epistemological work of science. To date, their classroom-based empirical work has focused on moment-to-moment analysis of small groups across different curriculum, as well as long-term analysis of one student's experiences across several years. While such work has revealed the integral role that students' affect and aims can play, it has not addressed the interplay between curriculum design, students' emergent affect-laden goals, and students' engagement in science disciplinary practices.

In my dissertation, I took a close look at the interplay between affect-laden goals and science disciplinary practices. Through a longitudinal analysis of two focal student pairs within the same curriculum, I documented several important findings related to students' desires, their affect-laden aims and motivations (Pea, 1993), and their engagement in science disciplinary practices. First, students' desires were integral to how the four students' engaged with the science practices supported in the curriculum. Such findings build on Jaber and Hammer's recent work, where they too documented the integral role that affect and aims played in students' science disciplinary pursuits. Second, my findings also reveal the variability of students' desires within the same curriculum, even within the same group. By examining two student pairs over time within the same curriculum, I was able to illuminate the variability of desires as they shaped students' engagement in science disciplinary practices. Such insights have not been possible in prior work that has focused on distinct moments with a few students or one student across time (Jaber & Hammer, 2016a, 2016b). Third, analysis shows how students' desires at times brought them into closer alignment with the purposes of ecologists' practices, while at other times moved them further away from these purposes. In sum, students' desires were an integral and consequential dimension shaping their learning opportunities.

Schoolyards are generative contexts for science inquiry. In my introductory chapter, I point to two lines of education research that suggest that everyday contexts can provide fertile ground for students as they engage with important ideas about their natural worlds. In my dissertation study, I intentionally leveraged both the materiality and complexity that everyday contexts offer, and the varied and rich knowledge children bring from their experiences in these familiar places.

Analyses in Chapter 4 and Chapter 5 point to the generative role the schoolyard space played, both for supporting students' reasoning about ecological systems and instigating disciplinary practices. In terms of student reasoning, the schoolyard space offered a complex ecological system for students to examine. Beginning with the curriculum's initial questions of "What is underfoot?" students considered multiple living and non-living parts as well as potential relationships among these parts unfolding over time. Students also drew on their everyday schoolyard knowledge, rich in sights, sounds, and smells of daily life (Nespor, 1997), to contextualize individual data points as students' reasoned about aggregate patterns in their data. Both the complexity of the schoolyard and children's rich and varied knowledge supported students wrestling with big ideas in ecology, such as different animals having different needs met in different niches (Lehrer & Schauble, 2012).

In terms of students' engagement in science disciplinary practices, the schoolyard afforded several benefits. First, the complexity and messiness of the space, in combination with the curriculum design, pushed students to wrestle with two key question in ecologists' sampling methodologies - what and where to sample. As scholars have noted, these are challenging and important questions that ecologists face in their own practice (Coe, 2008; Forsythe, 2018). Second, students used their detailed knowledge of the schoolyard as they conjectured and contested explanations using the aggregated data. This supported moving readily between schoolyard phenomena and reasoning about underlying processes and relationships, a movement at the core of science argumentation and reasoning (Latour, 1999).

Participatory GIS maps support communication and coordination. Recent research with participatory GIS mapping tools has pointed to the potential of these tools to support students leveraging their everyday experiences as they reason about complex relationships and processes (e.g., Headrick-Taylor & Hall, 2013; Rubel, Hall-Wieckert & Lim, 2017; Elwood & Mitchell, 2013; Van Wart, Lanouette & Parikh, 2016). Yet such mapping technologies are understudied with younger students and within science disciplinary practices such as modeling and argumentation. In the *Local Ground*-based curriculum design, the GIS participatory map supported late elementary students communications about their everyday schoolyard experiences as they reasoned with the classes' aggregated data

As evidenced in Chapter 4, several different aspects of students' map use supported late elementary students coordinating their everyday and data collection experiences as they conjectured and contested relationships and explanations using the aggregated class data. These included (a) students' use of gesture with the map to communicate and share their everyday schoolyard knowledge, (b) students' investigation of data across varying scales, volumes and formats and (c) blending together their schoolyard experiences and data using the maps.

Supporting students' sharing everyday knowledge using gestures and maps. Students often used gestures across the map surface to make visible their first-person knowledge of the schoolyard for others to see. In the process, students often evoked the movement on sunlight across the schoolyard, favored pathways for running, areas prone to flood in the rainy season and many other details steeped in children's everyday experiences. For example, recall in Chapter 4 Lena's sweeping hand gestures across the pond area to communicate and share shady areas near the pond sampling sites. In instances such as this, as well as many others like it, students used the maps in inventive and flexible ways to bring forth and share their everyday experiences with others.

Supporting students' investigation of data. The maps also supported students' active manipulation and consideration of data in varying scales, volumes and formats. With regard to scale, students were able to explore a close up investigation of the school garden, and in an instant, zoom out to view all 24 sampling sites across the schoolyard. With regard to volume, analyses in Chapter 4 show how students drew on varying volumes of data, such as one variable at one site to several variables at multiple sites. With regard to formats, students were able to move readily between different formats of data, from iconic symbols of select variables to text notes, sketches, and photographs. This ability to quickly create and critique so many different arrangements of their cross-site data supported exploring and explaining ecological systems at varied scales and volumes, a movement shown to be important in existing studies of students learning about ecological systems (e.g., Hmelo-Silver& Azevedo, 2006; Hmelo-Silver, Marathe & Liu, 2007) as well as sensemaking about complex socio-mathematical processes (e.g., Rubel et al, 2016; Wilkerson and Lania, 2018).

Such findings are consonant with existing research involving digital GIS maps but my analyses also contribute further insights. To date, existing research with digital GIS mapping tools has often focused solely on geographic scale in students' static map artifacts (Rubel et al., 2016). My study contributes a more nuanced examination of student use of data using GIS mapping tools, examining how multiple scales, volumes, and formats are leveraged simultaneously. This study also illuminates how student engagement with data may create rich grounds for reasoning in collective classroom discussions. Additionally, existing research with mapping tools has focused on scales at the neighborhood or city-level that are potentially more familiar to high school youth. In my dissertation study, which engaged late elementary age students, the scale movement took place over smaller intervals more familiar to this age group. Yet even these small shifts in scale resulted in important new perspectives that supported reasoning about ecological systems in generative ways. These findings suggest that the GIS mapping tools like *Local Ground* can play an important role in supporting younger students coordinating multiple data forms across scales, volumes and formats, even at smaller scales.

Supporting students integrating their everyday knowledge, schoolyard knowledge and field data in argumentation. Lastly, the maps supported a powerful blending together of students' everyday knowledge of the schoolyard and data. This blending supported going deep into the data, exploring complex multi-variate relationships and examining puzzling outliers. At the same time, this combination of experience and data often spurred extended discussions evoking additional dimensions of the schoolyard environments (e.g., foot traffic pathways, plants' growth and health). These conceptually rich blends of data and experiences often led to students reasoning about key ideas in ecology and attending to threats to the validity of their data.

Implications for Theory and Design of Science Learning Environments

In this section, I consider implications of my dissertation study both for theory and for the design of science learning environments.

Implications for Theory

This dissertation offers initial steps towards considering the intertwined nature of science disciplinary practices, students' desires, and classroom instructional design. Contemporary conceptualizations of science practices in the classroom have focused on the conceptual, social, epistemic, and material dimensions of science practice (e.g., Stroupe, 2015; Lehrer & Schauble, 2009). This dissertation study adds to this picture by pointing to the integral role of students' desires in shaping students' engagement in science disciplinary practices. Bringing together considerations in Jaber & Hammer's (2016a, 2016b) and Peas' (1993) work, my dissertation study reflects initial attempts to examine the intersection of learners' desires, science disciplinary practices, and instructional design. Yet analyses also point to further questions, such as how students' desires might shift across different science disciplinary practices. Additionally, the question arises: what is the interplay between students' desires and the types of uncertainty built into science curricular design?

In this dissertation, I drew on Saxe's form and function framework (Saxe, 2012). This framework offered a useful theoretical and methodological approach to studying how digital technologies can be adapted and transformed in use as part of classroom disciplinary activity. By focusing on different map forms, and the functions they serve in collective activity, this methodological approach made it possible to closely examine how specific *Local Ground* features were used in students' sense making about ecological relationships and processes. Analysis using this framework also illuminated the way the GIS maps and other representational forms afforded students opportunities to draw on their "everyday geographies" and their data collection experiences at local sites to reason about aggregated data. Lastly, it provided a unit of analysis that supported an interactional view of students' science argumentation processes.

Findings in this study also point to the distributed and varied resources students drew on in reasoning with the interactive maps. Such findings have parallels in Enyedy (2005) and Radinsky's (2010) conceptualization of students' map use, where they studied students' work with spatial data within a larger "semiotic ecology" that included maps, gesture and social interactions. In addition, my findings extend Enyedy and Radinsky's work, which focused mainly on interactions and experiences within the classroom walls. My dissertation study extends their work by detailing how students use the maps to coordinate their rich experiences across other times, spaces, and modalities beyond the classroom walls (e.g., Headrick Taylor, 2017). This expanding of the 'semiotic ecology', to include students' experiences beyond the classroom walls, offers a more complex understanding of how evidence might be constructed and contested using digital map forms. Parallels have been noted in studies of practicing scientists' work with maps and other representational forms(e.g., Hall, Stevens, & Torralba, 2002; Noss, Bakker, Hoyles, & Kent, 2007) but such cross-context movements are not often captured in classrooms studies.

Implications for Design of Science Learning Environments

Considerations of students' desires in curriculum design. As K-12 science instruction ideally comes to more closely resemble the knowledge-building practices of science, it will be crucial for teachers and curriculum designers to not only invite in but also support students in wrestling with the feelings and motivations that emerge as they engage in science disciplinary practices. These include not just the delight in unearthing wiggling invertebrates and finding animals, but also desires such as wanting to have the highest counts and competing against classmates.

Everyday places as contexts for students' science inquiry. As evidenced in this design, students' everyday contexts can be generative for both supporting challenging science learning opportunities and leveraging children's rich experiences beyond the school walls. Yet to do this work, practitioners will need support in learning about students' varied connections to and experiences in everyday contexts. This includes attending to multiple dimensions of students' experiences in everyday contexts, such as their affective, kinesthetic, and social experiences and understandings (Tuan, 1977; Hart, 1979: Barton & Lim, 2008). At the same time, practitioners will likely need assistance matching key concepts and science disciplinary practices to the particularities of immediate contexts. Both of these steps are consistent with teaching best practices (e.g., learning and engaging students' resources, elevating and supporting big ideas as center points for curriculum design) but will require providing additional support for teachers.

Participatory GIS maps within school communities. Philip and Garcia (2013) aptly describe how digital technologies are often presented in educational contexts as quick fixes to larger problems such as disjointed curriculum. As they describe it, both the pedagogical approaches (curriculum and teaching) and broader school context essential to meaningful use of technology in classroom contexts are obscured. This dissertation, with its combined focus on an innovative digital technology, curriculum design, teacher facilitation, and one school's outside yard space, offers a more nuanced look into the undergirding work integral to generative classroom learning with digital tools.

As science curriculum ideally continues to move beyond the "classroom as container" (Leander et al., 2010) model to engage with students' own rich life experiences, analyses in Chapter 4 and 5 point to the potential and challenge such digital tools present. Recall in Chapter 4 how *Local Ground* maps were often integral to students' conceptually rich classroom discourse. This included students' reasoning about complex science ideas and engaging in challenging data manipulations. Additionally, students' everyday experiences in a familiar context like the schoolyard were often seamlessly interwoven into their science argumentation, including often-marginalized forms of knowing in classroom contexts (e.g., kinesthetic, affective).

Yet there were also substantial challenges to supporting such generative learning contexts. One challenge was the time and experience it took to create a curriculum that wove together big ideas on science with the particular resources of the students and their surrounding places. This included time to learn more about students' experiences and the resources inherent to the schoolyard, as well as experience in creating curriculum to support students' engagement in science disciplinary practices around core ideas. Additionally, supporting students' argumentation with the GIS maps involved careful preceding work in earlier class activities to organize data collection activities around big ideas in science. As such, participatory GIS maps and related spatial data tools will require thoughtful leveraging of teachers' expertise in order to meet their potential in formal education contexts.

Limitations and Promising Directions for Future Research

In the design of the dissertation study, several limitations suggest areas for future research. I organize the limitations and future research into two sections - research methods and instructional design.

Research methods. While my research methods allowed me to gather extensive data on student and teacher activity at multiple scales (individual, dyads, small group, and whole class), there were several limitations that suggest future consideration that can be addressed in subsequent research.

Small sample size. One limitation was the small sample size. This study involved one 5th grade class (n = 27) at one grade level in one school. In addition, one line of analysis focused on three class sessions within this study and a second analysis focused on two student pairs (n =4). This sample size was a strategic place to start to examine my research questions but does not provide the basis for generalizations or definitive conclusions. In future work, it would be productive to explore my research questions involving a larger sample size, with additional grades or multiple school sites.

Multiple roles: Designer, teacher, and researcher. A second methodological limitation was the multiple roles I played in the research project - designer, teacher, and researcher. While wearing these multiple 'hats' had several benefits, it was challenging at times to do all three roles well. For example, in early lessons, it took time for me to develop a rapport with the 5th grade class, despite earlier class visits. In future research, it will be useful to either more fully immerse myself in each role, particularly the teaching role, or else to step back from the lead instructional role and focus more on design and research. To strengthen my teaching role, it would be important to get to know the teachers, students, and families in the school community even further, through sustained participation in the school community.

Alternatively, it would also be productive to relinquish the teaching role, supporting and studying early career and experienced teachers in designing science curriculum around the resources unique to their students and community spaces as well as key concepts and practices delineated in the Next Generation Science Standards. By building on teachers' existing experiences and expertise, it would likely be possible to develop more robust curriculum rooted in the particular strengths, needs, and histories of the school community and its students.

Regarding the researcher role, it would also be useful to have a dedicated researcher recording field notes in each class session. This additional data source would provide another perspective on classroom activities complementing the teachers, useful in shaping emergent adaptations to curriculum. Such notes would also provide a more detailed record of activity, available more readily in the midst of data collection compared to the video record which required time intensive review and logging.

Data collection and design. A third methodological limitation concerns the types of data I was able to collect. Existing data sources were extensive and enabled me to triangulate claims and evidence yet it was challenging to study shifts in learning over time as well as to make comparisons within the curriculum.

Student learning over time. Given students' engagement in cycles of ecologist' practices to support learning about ecological systems, it would have been helpful to have starting, mid-point and ending measures on how students were potentially shifting in their reasoning about both ecological systems and the science practices in which they were participating. For example, I was able to collect repeated data on students' site selection rationales, in written text, whole class discussions and focal student interviews at the start of each cycle of ecologists' practices.

Additional outcome measure data, such as pre and post assessments and exit slips across lessons, would be helpful to further study changes in student reasoning about ecological systems. Additionally, similar measures collected from a non-participating class would be an additional beneficial perspective for understanding student learning trajectories within this designed curriculum.

Making comparisons within the curriculum. In light of my research focus on the potential of the interactive GIS maps in whole class discussions, it would have been useful to compare students' coordination of their everyday schoolyard knowledge and data collection experiences with other representational forms used in the curriculum, such as the paper data maps or canonical forms typically associated with descriptive displays of numerical data (e.g., two-way table and the multi-variable bar charts). In future research, it would be useful to create more parallels for whole class and small groups discussions across the varied data forms, to support comparisons in discussions using the digital GIS maps in contrast to canonical forms.

Instructional design. Multiple decisions were made in the design of both the curriculum and the *Local Ground* mapping tool. I reflect here on several limitations that suggest future consideration that can be addressed in subsequent research.

Schoolyard soil ecology as context for study. One design limitation was selecting students' schoolyard soil ecology as a context for study. While this context offered many productive aspects, it represented only a small slice of children's "everyday geographies" (Elwood & Mitchell, 2013). In future research, it would be useful to consider broadening the scale to include other places central to student's lives, such as their home neighborhoods and other meaningful contexts they identify. By expanding the scale, it might be possible to leverage a wider spectrum of students' experiential knowledge in their science sense making as well as other types of ecological systems (e.g., water system). Or alternatively, it would be useful in future research to dig deeper into schoolyard site itself, supporting bringing forth more of children's schoolyard knowledge and experiences and linking this space with other intersecting ecological systems.

This decision of context and scale also had implications for how the *Local Ground* maps were used (and not used) by students. As noted in Chapter 4, there were times when students wanted to zoom in more fully or change to an on-the-ground perspective. Yet given the limits of the Google maps interface, students were limited in how close in they could zoom and in the perspectives they could take. Had we explored a larger spatial area, and one accessible by the street, students would have been able to toggle between explorations of the data at varying scales and shifting to an on-the-ground perspective. In future research, it would be useful to consider designs to a curriculum that work better with the limits of the Google maps. Alternatively, for a focus on smaller scales, future research might involve "balloon mapping" techniques (Wylie, Jalbert, Dosemagen, & Ratto, 2014) that generate photograph maps at smaller scales using balloons and cameras flown overhead. Using this approach, any context can be a basis of inquiry, regardless of scale or access.

Audience, explanation and action. The second design limitation concerns the audience for students' science pursuits, particularly as students engage in explanation and science argumentation using their aggregated data. While Chapter 4 analyses reveal students engaging in complex conversations coordinating data, experiences and explanations with one another, it would be useful to explore how students' argumentation and use of data changes as both the audience and the purpose for argumentation shift. For example, imagine if students' aggregated data and explanations in this curriculum could be integral to land use decisions at the school community and neighborhood level. In the original design of this curriculum, an intended (but unrealized) design was for students to share findings with other classes, teachers and the school principal. The aim was for students to not only share relationships and explanations with their classmates but to use their empirical findings and maps to suggest consequential actions, such as schoolyard redesign suggestions to support more organisms thriving (see Chapter 2, Framework questions). Given calls for curriculum design to support the *need* for science practices such as science argumentation (Manz, 2016), it seems generative to further consider how audience and the potential actions possible through such argumentation can further instigate and stabilize science disciplinary practices.

To conclude**,** by exploring the intersection of students' engagement in science through participatory GIS mapping, my dissertation research aims to contribute to the development of conceptually rich contexts for elementary students' science learning in schools and the surrounding everyday spaces central to children's lives. This work contributes to the fields' understanding of *how* we might engage students in science disciplinary practices, in ways that productively build on children's extensive experiences and varied perspectives while engaging students in the challenge and delight of science pursuits.

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Appendix A
Semi-structured Interview Protocols

Focal students (n=6) were interviewed individually at four points across the study. These interviews had several purposes. One purpose was to better understand students' reasoning about their selected sampling sites in the schoolyard, the sampling methodologies used in their data collection, and their perceived usefulness of sampling in sites with low or zero counts. A second purpose was to understand how students interpreted and made use of the varying representational forms (see Table 23 below). A third purpose was to see if there were shifts in students' reasoning about the sampling methods across cycles, particularly in regards to the usefulness of sampling at sites that yielded zero or few counts of organisms. This was accomplished by repeating the same Question in each interview about sampling at sites yield low or zero counts. A fourth purpose was to see how reasoning with the representational forms might vary as the forms shifted. This was accomplished by shifting the representational forms used in the interviews

Table 23
Interview Timing and Shifting Representational Forms

Interview	Representational Form
Interview 1: prior to first cycle data collection	Color photograph map
Interview 2: after 1st round of data collection	Paper data map
Interview 3: after 2nd round of data collection	*Local Ground* map
Interview 4: post curriculum	Color photograph map, paper data map, *Local Ground* map, two-way table, bar chart

Interview #1: Color Photograph Map

<u>Protocol (prior to 1st cycle of data collection)</u>
Materials:

- binder with plastic map of school yard
- larger color photograph map
- image of parts of ecosystem (with above and below ground variables)
- prior student's work: initial site selection sheet (where children described sites of interest and their rationale for why they want to study those sites)

Prompts:

- Tell me more!/ I am interested in your thinking!/ Why do you say that?

<u>Background</u>
Question 1: How long have you been a student here? What grade did you start in?

<u>Interpretation of form (color map)</u>
Question 2a: Show me _____ classrooms?
Question 2b: Are any parts of the map confusing or hard to figure out what they are?
Question 2c: How do you enter and leave the school each day?

<Interviewer briefly reviews framework curriculum Question s and parts of ecosystems above and below ground that students have been discussing>

<u>Site selection rationale</u> (based on students' earlier written responses on site selection sheets)
Question 3: Can you tell me more about why you thought _______ was a good spot to study?

<u>Sampling Question (usefulness of zero or low counts)</u>
Question 4: I noticed as I looked through everyone's ideas about where to study that most students choose places where there were LOTS of plants or animals. I was curious if you thought it would be useful to study places where there are NOT many plants or animals? (Why?)

<u>Specific site selection rationale and predictions</u>
Question 5a: Will you show me on the big map, where did you and your partner decide to study? Why did you decide on this spot to study?
Question 5b: What do you expect to find at your site? Why?
Question 5c: What do you think the soil will be like? Why?

<u>Wrap up</u>
Question 6: Do you have any Question s for me or any comments or feedback?

Interview #2: Paper Data Map

Protocol (after 1st round of data collection)

Materials:

- Focal students' binders with small aggregated paper data map copy
- Large class aggregated paper data map propped up

Prompts:

- Tell me more!/ I am interested in your thinking!/ Why do you say that?

Opening statement:
Today I am interested in learning more about your thinking and using the **paper data maps** we've made in science class. There are no right or wrong answers – I am just interested in what you notice and having you share your thinking and Question s with me! Do you have any Question s or comments before we start?

Interpretation of form (aggregated paper map)
Question 1a: Take a look at the map! Can you show me where is your classroom? The school garden? Your site?

Question 1b: Choose one site and tell me what they found there.
Prompt if stuck: What do the different numbers and color stickers show here [pointing to one site]?

Identification of relationships and explanations
Question 2: Now let's look at the whole map! Do you see any patterns or relationships? Why do you think that is? Or do you see any patterns and then something that breaks the patterns?

Prompt if stuck (or only offer one pattern): Do you see any sites that are the same? In what ways are the sites the same? Why do you think that is? [Do you think any of the sites are the same in other ways? Where? Why do you think?]

Prompt if stuck (or only offer one pattern): Do you think any of the sites are different? In what ways are they different? Why do you think that its? {DO you think any of the sites are different in other ways? Where? Why do you think?]

Puzzles? Surprised? Question s? Uncertainty?
Question 3a: Does anything looking puzzling or confusing in this data?
Question 3b: Did anything surprise you? What? Why?
Question 3c: We all gathered data at our different sites over these last few weeks. Do you think our data could be wrong in any ways? If yes, in what ways?

Example and counter example
Question 4a: Looking at the pond area, one child noticed that few earthworms and other invertebrates were found in this space? Why do you think that is?

Question 4b: Why do you think this one group DID find lots of organisms (pointing to a spot in the pond area that had a higher earthworm count)?

Next step site selection

Question 5a: Based on the patterns and puzzles you are seeing here in your data map, what new places would you want to explore next? (Show me on the map)

Question 5b: Why would you think these are good places to study further?

Prompt: What makes you interested in study these spots?

Sampling Question (usefulness of zero or low counts)

Question 6 : I noticed there are sites with LOTS of plants or animals or other sites with very few or NONE. I was curious if you thought it would be useful to study places where there are NOT many plants or animals? (Why?)

Wrap up:

Question 7: Do you have any Questions for me or anything else you want to share?

Interview #3: Digital Data Map (*Local Ground*)

Protocol (after 2nd round of data collection)

Materials:

- Laptop computer with *Local Ground* digital map
- image of ecosystem parts chart (showing living/ non living and above/ below ground variables)

Prompts:

- Tell me more!/ I am interested in your thinking!/ Why do you say that?

Introductory Statement:

- Today I am interested in learning more about your thinking and using the **digital maps** we've made in science class. There are no right or wrong answers – I am just interested in what you notice and having you share your thinking and Question s with me! Do you have any Question s or comments before we start?

Interpretation of form (digital data map)

Question 1a: Take a look at the map! With the mouse, can you show me where is your classroom? your first site? your second site?

Question 1b: Choose one other site and tell me what they found at their site!

- Prompt if student only looks at one variable or just one variable layer: Is there any more you can find out about this particular site?

Identification of relationships and explanations

Question 2: Now let's look at the whole map! We have been talking a lot about the parts of the schoolyard we have studied and exploring how the different parts might be interconnected.

Question 2a: As you look at this map of everyone's data, do you see any patterns or relationships? Why do you think that pattern is happening?

- Prompt if stuck (or only offer one pattern): Do you see any sites that are the same? In what ways are the sites the same? Why do you think that is? [Do you think any of the sites are the same in other ways? Where? Why do you think?]
- Prompt if stuck (or only offer one pattern): Do you think any of the sites are different? In what ways are they different? Why do you think that its? {DO you think any of the sites are different in other ways? Where? Why do you think?]

Question 2b: As you look at this map of everyone's data, do you see a pattern and then something that breaks the pattern? Why do you think this break in the pattern in happening?

Puzzles? Surprised? Question s? Uncertainty?

Question 3a: Does anything look puzzling or confusing in this data? Tell me more!

Question 3b: Did anything surprise you? What? Why?

Question 3c: We all gathered data at our different sites over these last few weeks. Do you think our data could be wrong in any ways? If yes, in what ways?

Example and Counter example

Question 4a: Looking at the pond area, one child noticed that few earthworms and other invertebrates were found in this space (pointing to high traffic area)? Why do you think that is?

Question 4b: Why do you think this one group DID find lots of organisms (pointing to a spot in the pond area that had a higher earthworm count and less foot traffic)?

Next step site selection

Question 5a: Based on the patterns and puzzles you are seeing here in your data map, what new places would you want explore next? (Show me on the map with your mouse)

Question 5b: Why would you think these are good places to study further?

- Prompt: What makes you interested in study these spots?

Sampling Question (usefulness of zero or low counts)

Question 6: I noticed there are sites with LOTS of plants or animals or other sites with very few or NONE. I was curious if you thought it would be useful to study places where there are NOT many plants or animals? (Why?)

Wrap up:

Question 7: Do you have any Question s for me or anything else you want to share?

Interview #4: All Representational Forms

Protocol (post curriculum)

Materials:

- Laptop computer with *Local Ground* digital map
- Image of ecosystem parts chart (showing living/ non living and above/ below ground)
- Chart with framework Question s
- Chart showing all representational forms overlaid on curriculum timeline
- 8 ½ x 12 color images of all representational forms (color photograph map, paper data map, digital map, two way table, bar chart)

Added purposes of this interview: I would like this interview to engage students in using and reflecting on multiple data forms all together, not in isolation like the prior 3 interviews. I also want to engage students in reflections on participating in the instructional design, specifically what changes they would make to the science inquiry structure/ procedures and the related rep forms.

Prompts: Tell me more! I am interested in your thinking! Why do you say that? **

Introduction

Today, it is our last interview together. As before, there are no right or wrong answers. I am excited to hear your thinking about the Question s I have. Do you have any Question s *for me* before we start?

Section I: Project review and redesign (form/ function)

This spring, we have been exploring your schoolyard over many weeks, looking at the parts underground and above ground, and talking about the ways they might be connected using paper and digital maps as well as different bar charts.

Recall that we were focusing on learning more about several "big" Question s over these weeks [*pointing to chart of framework Question s]:*

What is underground?
In what ways are the parts connected?
Why might this be?
How can we find out more?
What can we do in our school neighborhood?

Working in pairs of two or threes, everyone spread out, choosing sites of interest to study more. You and your classmates collected information about the **animals** that lived in different spots underground, by digging in the earth (show picture of students digging) and by setting pitfall traps (show image of pitfall traps). You also recorded the amount of **moisture** in the soil by squeezing it, noting wet, moist or dry (show picture) and how **compact** the soil was, by pouring water through a cup and timing how long it took to sink in to the ground (show picture). You also observed what the soil was like, including the **color** and **composition**, by looking closely and describing what was in it (ex. rocks, twigs, sand, woodchips). You took sketches and photographs of what you saw. As we worked, we explored our data in lots of ways, using a map, sticker map, invertebrate post-it chart, sticker bar charts, and the digital Local Ground maps [*point to timeline image that shows different representational forms*]

Imagine now that YOU could lead the design of this science project, changing the design in places to better support students exploring the big Question s here at _____ school.

Site Location Prompt:
We looked in over 20 different spots, with a few groups repeating the same site twice.
Question 1: Do you think it is important for students to be able choose their spots like you and your partner did? Why or Why not?

- IF YES: would you recommend any spots? Why?
- IF NO: where would you assign them?

Sampling Question (usefulness of zero or low counts)
Question 2: During this project, some students only wanted to look in places where they would find LOTS of plants or animals. What do you think about that? Do you agree or disagree?

- If all the students wanted to look in sites where there are lots of animals, do you think this might be a problem for answering the big Question s? Why?

Methods and Tools Prompt:
We gathered lots of data using different tools and techniques.
Question 3: Would you gather ALL of this data again? or only some of it?

- Follow up: was some of the data more useful to you than others?
- Is there any data that we didn't collect that you think would be useful? Why?

Question 4: We gathered two rounds of data. How many times would you recommend having students collect this data at a site? Why?

Representation Prompt:
We used many different visual images to think about the different parts above and below ground and possible relationships between them.
Question 5: Were any visual images particularly helpful for thinking about these parts and relationships? In what ways? (show all the forms in a line)
Question 6: Let's take a look at specific ones....Would some ways of looking at data be better than others in helping to think about parts above and below ground and the relationships between them? What kinds of relationships did you see?

    - Sticker Map
    - Invertebrate Chart
    - Bar Chart
    - Digital Map

Question 7: Zero turned out to be important in our pattern finding, like places with no earthworms or invertebrates or no students playing there or no puddles ... do you feel like some forms made it easier to see low counts or find nothing? Did some forms make it harder to see this?

Section II: Written Survey Questions

Take out students' written responses to the summative written survey (see Appendix B)

Question 8: Tell me about your answer for Question #2. What did you write? Tell me more about your thinking!

Question 9: Tell me about your answer for Question #3. What did you write? Tell me more about your thinking!

Question 10: Tell me about your answer for Question #4. What did you write ? Tell me more about your thinking!

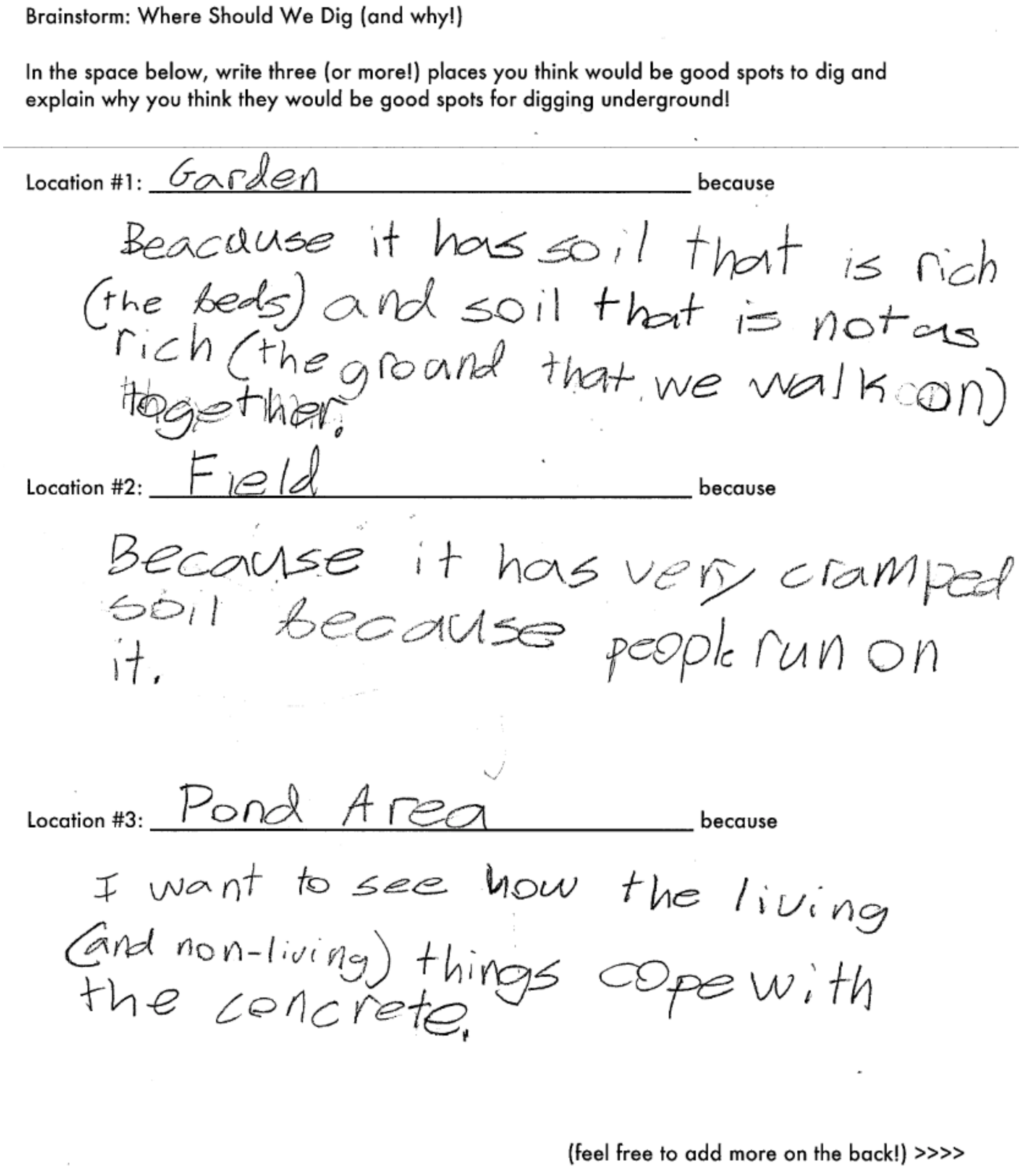
Section III: Wrap up

Question 11: Did this project feel different than what you usually do in school – and science? Tell me more!

Question 12: Is there anything else you want to share or ask before we wrap up?

Appendix B
Focal Student Artifacts

In Appendix B, I include student artifacts related to Chapter 5 analyses. I present select focal student's written artifacts. Written artifacts include (a) the Site Brainstorming Sheet (lesson 1) for Max and Lena, (b) the First Site Selection Sheet (lesson 3) for Amir, (c) the Data Collection Field Notes for Marie (lesson 5), (d) the Second Site Selection Sheet for the Marie and Lena (lesson 13) and (e) the post-instruction Written Assessment for Lena (post lesson 18).



Brainstorm: Where Should We Dig (and why!)

In the space below, write three (or more!) places you think would be good spots to dig and explain why you think they would be good spots for digging underground!

Location #1: Garden because

Beacause it has soil that is rich (the beds) and soil that is not as rich (the ground that we walk on) together.

Location #2: Field because

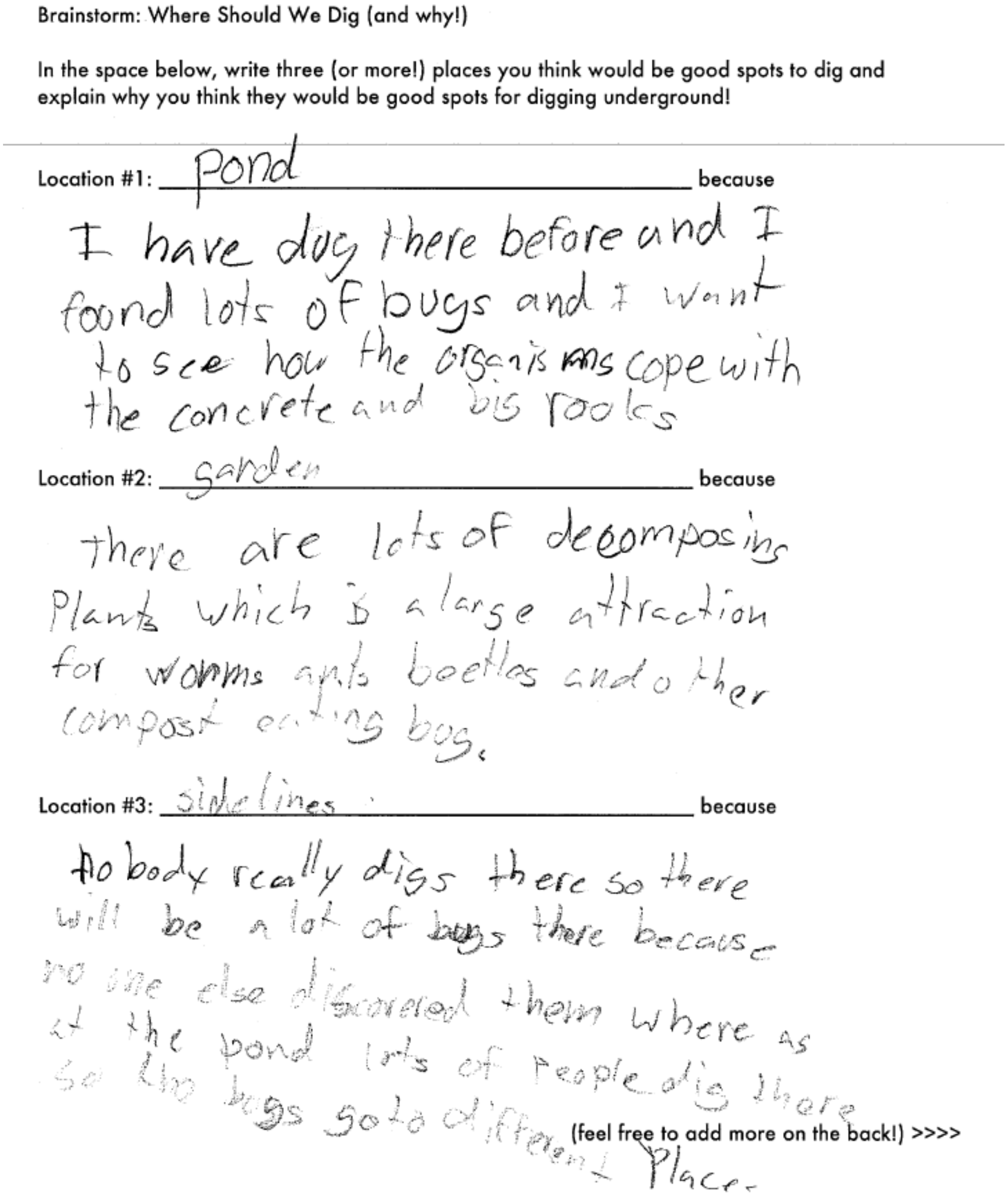
Because it has very cramped soil because people run on it.

Location #3: Pond Area because

I want to see how the living (and non-living) things cope with the concrete.

(feel free to add more on the back!) >>>>

Figure X. Site Selection Brainstorm Sheet for Max (Lesson 1)



Brainstorm: Where Should We Dig (and why!)

In the space below, write three (or more!) places you think would be good spots to dig and explain why you think they would be good spots for digging underground!

Location #1: pond because

I have dug there before and I foond lots of bugs and I want to see how the organisms cope with the concrete and big rooks

Location #2: garden because

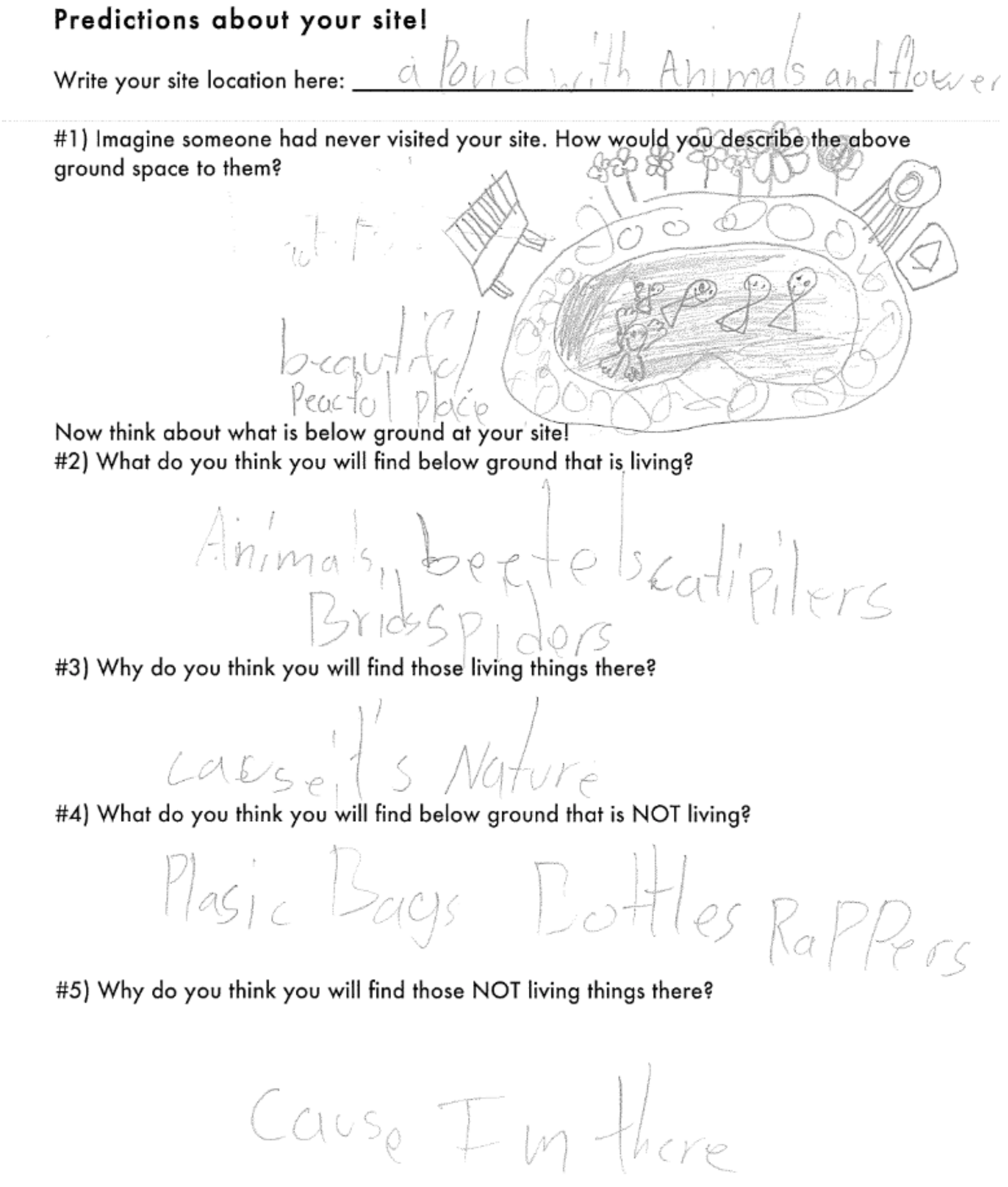
there are lots of decomposing plants which is a large attraction for worms ants beetles and other compost eating bugs.

Location #3: sidelines because

nobody really digs there so there will be a lot of bugs there because no one else discovered them where as at the pond lots of people dig there so the bugs go to different place.

(feel free to add more on the back!) >>>>

Figure X. Site Selection Brainstorming Sheet for Lena (Lesson 1)



Predictions about your site!

Write your site location here: a Pond with Animals and flower

#1) Imagine someone had never visited your site. How would you describe the above ground space to them?

beautifcl Peacfol place

Now think about what is below ground at your site!

#2) What do you think you will find below ground that is living?

Animals, beetels catipilers Bridspiders

#3) Why do you think you will find those living things there?

cause it's Nature

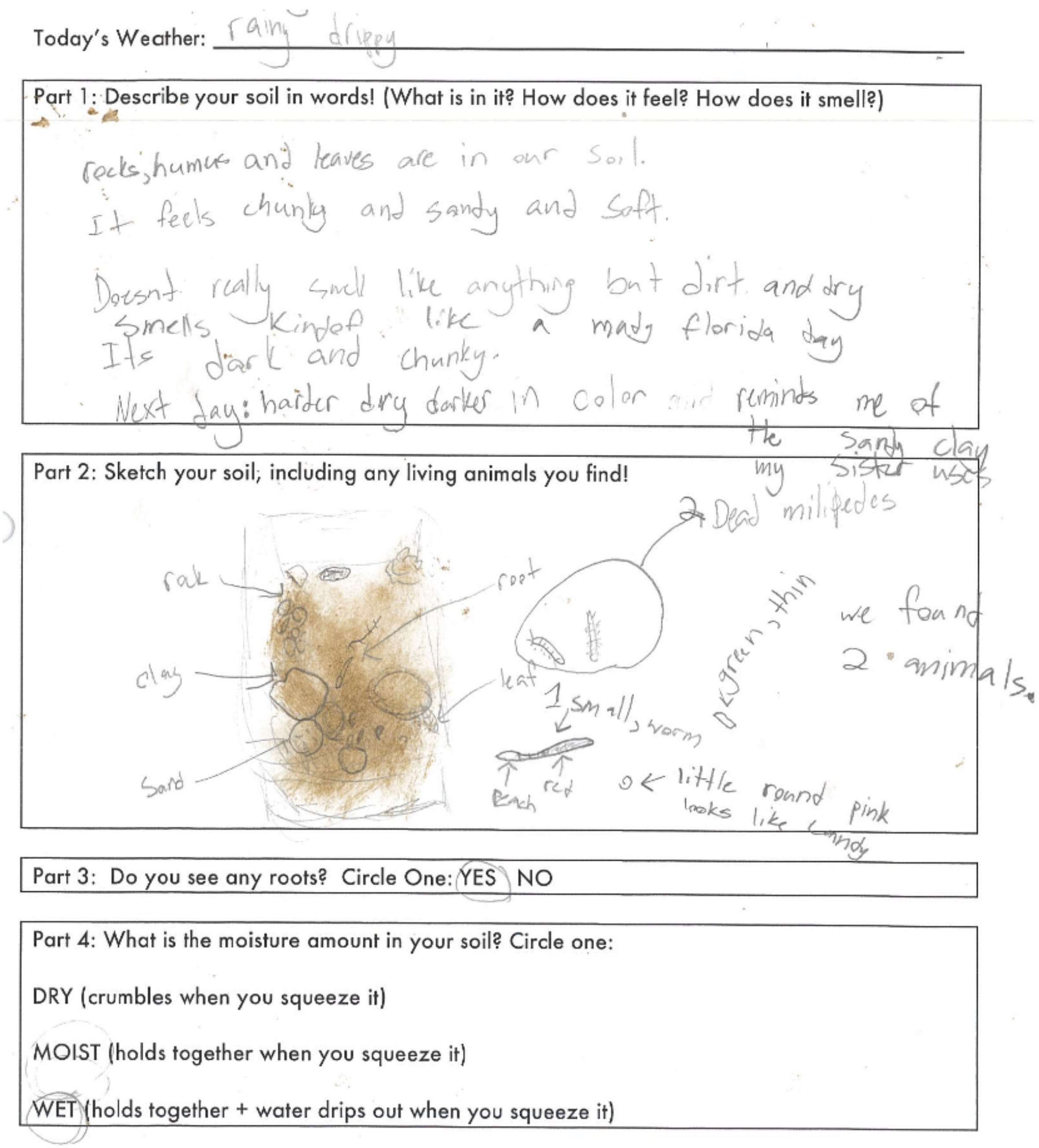
#4) What do you think you will find below ground that is NOT living?

Plasic Bags Bottles RaPPers

#5) Why do you think you will find those NOT living things there?

Cause I'm there

Figure X. Amir's Site Prediction Sheet (Lesson 3). Note affective descriptions of the pair's proposed sampling site.



Today's Weather: rainy drippy

Part 1: Describe your soil in words! (What is in it? How does it feel? How does it smell?)

rocks, humus and leaves are in our Soil.

It feels chunky and sandy and Soft.

Doesnt really smell like anything but dirt and dry smells kindof like a mady florida day

Its dark and chunky.

Next day: harder dry darker in color and reminds me of the Sandy clay my Sister uses

Part 2: Sketch your soil, including any living animals you find!

we found 2 animals.

Part 3: Do you see any roots? Circle One: [✓ YES] NO

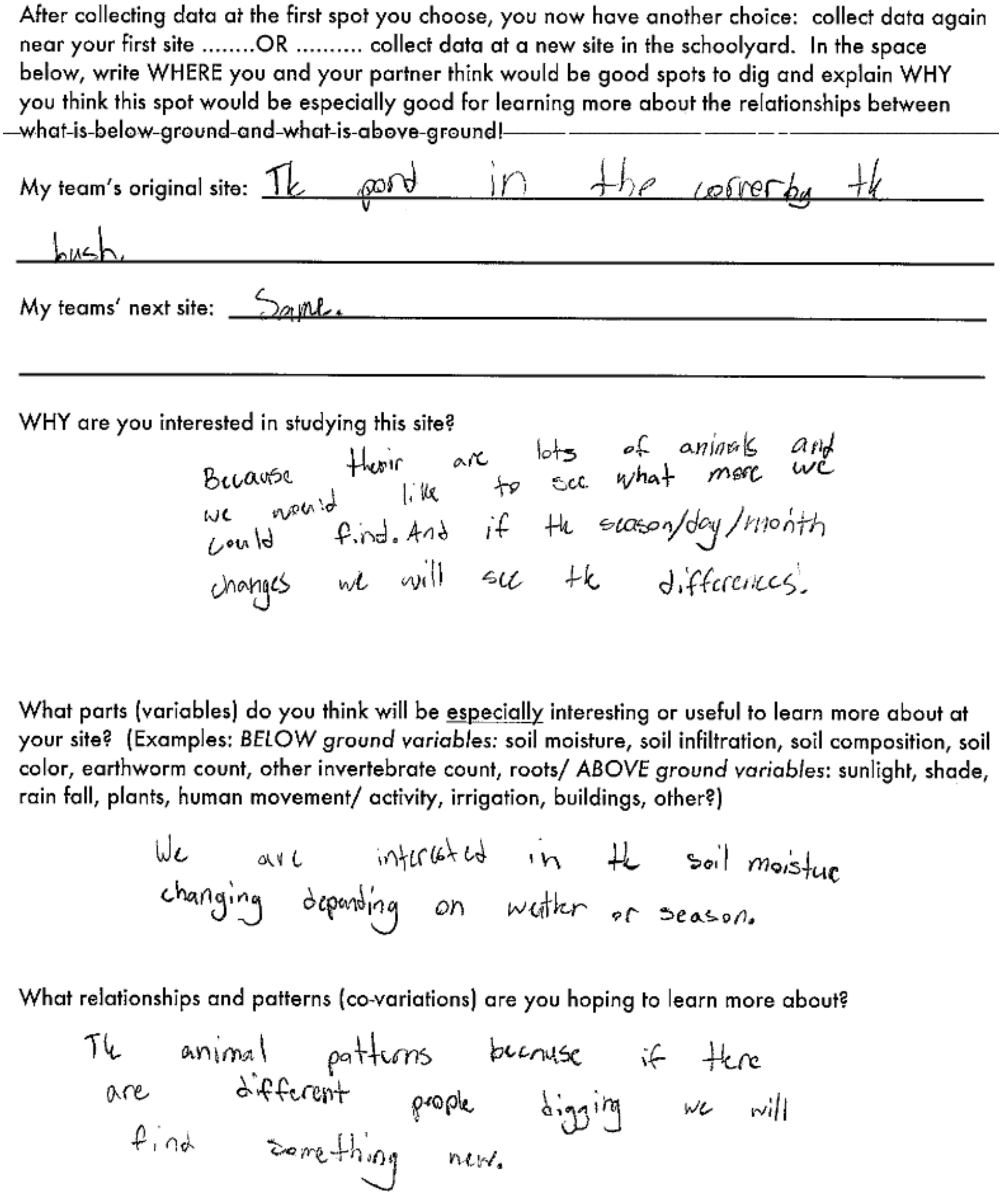
Part 4: What is the moisture amount in your soil? Circle one:

DRY (crumbles when you squeeze it)

MOIST (holds together when you squeeze it)

[✓ WET] (holds together + water drips out when you squeeze it)

Figure X. Marie's Data Collection Sheet (Lesson 5)



After collecting data at the first spot you choose, you now have another choice: collect data again near your first site ....OR .... collect data at a new site in the schoolyard. In the space below, write WHERE you and your partner think would be good spots to dig and explain WHY you think this spot would be especially good for learning more about the relationships between what-is-below-ground-and-what-is-above-ground!

My team's original site: The pond in the corner by the bush.

My teams' next site: Same.

WHY are you interested in studying this site?

Because their are lots of animals and we would like to see what more we could find. And if the season/day/month changes we will see the differences.

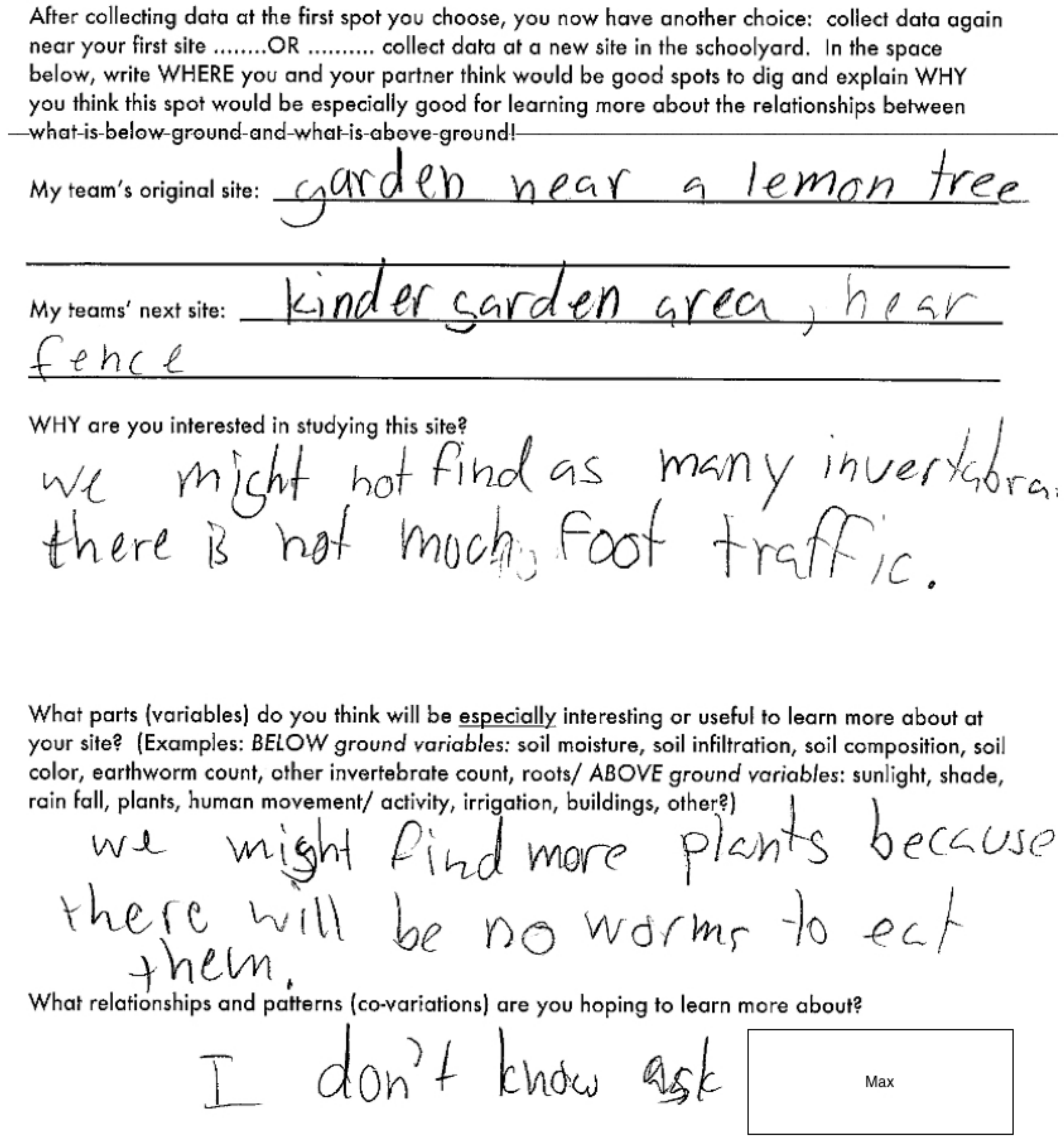
What parts (variables) do you think will be especially interesting or useful to learn more about at your site? (Examples: *BELOW ground variables:* soil moisture, soil infiltration, soil composition, soil color, earthworm count, other invertebrate count, roots/ *ABOVE ground variables:* sunlight, shade, rain fall, plants, human movement/ activity, irrigation, buildings, other?)

We are interested in the soil moistue changing depanding on wether or season.

What relationships and patterns (co-variations) are you hoping to learn more about?

The animal patterns because if there are different people digging we will find something new.

Figure X. Marie's Site Selection Rationale Sheet (Lesson 13). Note interest in sampling site includes finding lots of animals and seeing potential differences due time passing.



After collecting data at the first spot you choose, you now have another choice: collect data again near your first site ....OR .... collect data at a new site in the schoolyard. In the space below, write WHERE you and your partner think would be good spots to dig and explain WHY you think this spot would be especially good for learning more about the relationships between what-is-below-ground-and-what-is-above-ground!

My team's original site: garden near a lemon tree

My teams' next site: kinder garden area, near fence

WHY are you interested in studying this site?

we might not find as many invertabra there is not much foot traffic.

What parts (variables) do you think will be <u>especially</u> interesting or useful to learn more about at your site? (Examples: *BELOW ground variables:* soil moisture, soil infiltration, soil composition, soil color, earthworm count, other invertebrate count, roots/ *ABOVE ground variables*: sunlight, shade, rain fall, plants, human movement/ activity, irrigation, buildings, other?)

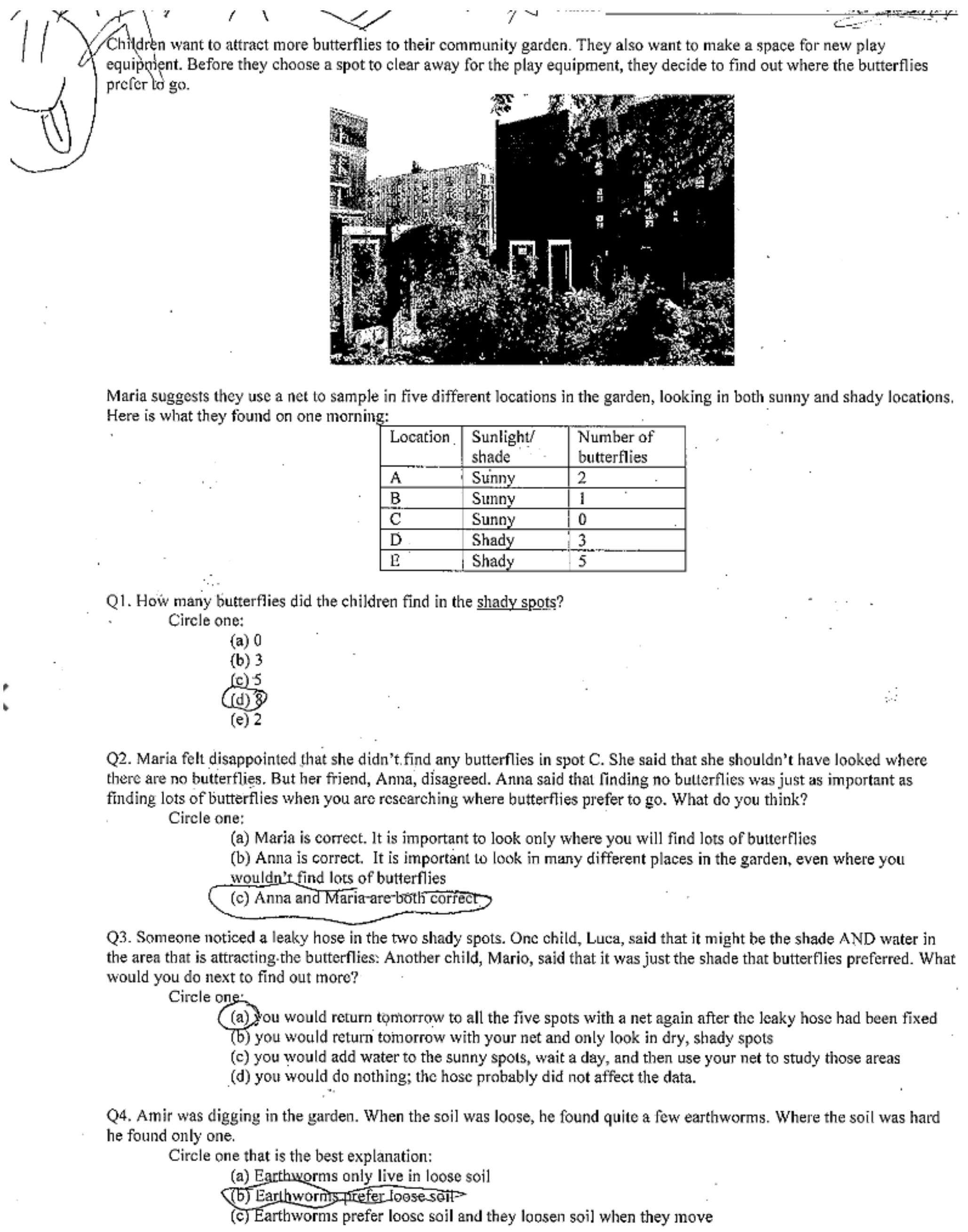
we might find more plants because there will be no worms to eat them.

What relationships and patterns (co-variations) are you hoping to learn more about?

I don't know ask

Max

Figure X. Lena's Site Selection Sheet (Lesson 13)



Children want to attract more butterflies to their community garden. They also want to make a space for new play equipment. Before they choose a spot to clear away for the play equipment, they decide to find out where the butterflies prefer to go.

Maria suggests they use a net to sample in five different locations in the garden, looking in both sunny and shady locations. Here is what they found on one morning:

Location	Sunlight/ shade	Number of butterflies
A	Sunny	2
B	Sunny	1
C	Sunny	0
D	Shady	3
E	Shady	5

Q1. How many butterflies did the children find in the <u>shady spots</u>?

Circle one:

(a) 0
(b) 3
(c) 5
[✓ (d) 8]
(e) 2

Q2. Maria felt disappointed that she didn't find any butterflies in spot C. She said that she shouldn't have looked where there are no butterflies. But her friend, Anna, disagreed. Anna said that finding no butterflies was just as important as finding lots of butterflies when you are researching where butterflies prefer to go. What do you think?

Circle one:

(a) Maria is correct. It is important to look only where you will find lots of butterflies
(b) Anna is correct. It is important to look in many different places in the garden, even where you wouldn't find lots of butterflies
[✓ (c) Anna and Maria are both correct]

Q3. Someone noticed a leaky hose in the two shady spots. One child, Luca, said that it might be the shade AND water in the area that is attracting the butterflies. Another child, Mario, said that it was just the shade that butterflies preferred. What would you do next to find out more?

Circle one:

[✓ (a) you would return tomorrow to all the five spots with a net again after the leaky hose had been fixed]
(b) you would return tomorrow with your net and only look in dry, shady spots
(c) you would add water to the sunny spots, wait a day, and then use your net to study those areas
(d) you would do nothing; the hose probably did not affect the data.

Q4. Amir was digging in the garden. When the soil was loose, he found quite a few earthworms. Where the soil was hard he found only one.

Circle one that is the best explanation:

(a) Earthworms only live in loose soil
[✓ (b) Earthworms prefer loose soil]
(c) Earthworms prefer loose soil and they loosen soil when they move

Figure X. Lena's Written Survey, referenced in Chapter 5 analysis.

Appendix C
Whole Class Presentations Using *Local Ground* Maps

This chart reflects phase one of my analysis process discussed in Chapter 4. In this table, a research assistant and I recorded each presenting pair's opening conjecture, the data used in this conjecture (Number of variables, volume, format) and how the map form was used during this phase.

Lesson	Pair Presentation	Opening Conjectures	Data Used in Opening Conjecture			Map Use in Opening Conjecture
			Variables	Volume	Format	Scale
16	Pair 1 Jacob and Gal (38:20 – 41:10)	Earthworms prefer the garden given all the moist soil	3 variables, earthworm count, location, Soil moisture	All sites	Iconic	Entire schoolyard
	Pair 2 Mia and Taye (42:05 - 46:45)	Surprised that dry and moist soil sites both have fast infiltration times, as they expected dry soil would have the fastest infiltration times	4 variables, soil moisture, infiltration, earthworm count, shade	All sites	Iconic	Garden
	Pair 3 Lena and Max (1:10:20 - 1:19:00)	Earthworms thrive when there is moist soil, roots and shade	5 variables, location, trees, shade/sun, earthworm count, shade, soil moisture,	Garden sites, pond sites, their own site	Iconic	Garden Pond Sports field
	Pair 4 Kevin and Darius (1:21:10 - 1:26:15)	Surprised earthworms were found across the entire schoolyard given differences in plants, animals and people activities	4 variables, earthworm count, location, shade, flooding	All sites	Iconic Qualitative	Garden Pond Sports field
17	Pair 5 Mary and Miles (13:00 – 21:200)	Surprised an earthworm was found at a particular site, because it often floods in that area	3 variables, earthworm count, flooding, soil moisture	1 site	Iconic Qualitative	Blacktop
	Pair 6 Ellie and Luis (22:30 - 35:00)	Invertebrates other than earthworms need moist soil to thrive	3 variables, earthworm count, soil moisture, cob bench	Pond sites	Iconic Qualitative	Pond

	Pair 7 Nora, Myisha, and Rosalina (37:10 - 44:30)	Earthworms don't just like moist soil but also dry soil, arguing that soil compaction and the temperature of the soil might be important aspects to consider as well	5 variables, invertebrate count, location, earthworm count, soil moisture, soil temperature	Garden sites	Iconic	Garden Sports field
18	Pair 8 Amir and Marie (14:10 - 25:00)	Our sampling site is the only place that had lots of earthworms, wet soil and fast infiltration rates. Wondering if fast infiltration rates is connected to more earthworms because maybe the earthworms can move more freely in the looser soil	3 variables, earthworm count, soil moisture, infiltration	Garden sites	Iconic	Pond
	Pair 9 John and Aiden (6:10 - 12:00)	Expected a relationship between fast infiltration rates and root but there were several sites that had long infiltration times and roots.	3 variables, infiltration rate, roots, tree	All sites	Iconic Qualitative	Entire schoolyard
	Pair 10 Isaac and Priya (12:50 - 31:20)	Earthworms don't necessarily need moist soil, shade, and roots, using their site and another site with similar conditions, expect for earthworm counts	4 variables, Soil moisture, shade, plants, earthworm count	Two sites	Iconic	Two sites – garden and sports field
	Pair 11 Elizabeth and Maurice (32:40 - 36:00)	Wet soil has a lot to do with longer infiltration rates because wet soil already has so much water in it and it can't take any more, like a sponge.	2 variables, soil moisture, infiltration rate	Pond sites	Iconic	Pond