Supporting Elementary Students’ Science Learning Through Data Modeling and Interactive Mapping in Local Spaces

Abstract: Our work is based on three premises: (a) children’s experiential, everyday knowledge about local spaces is a rich resource for science learning, (b) involvement in data modeling contributes to children’s conceptual understanding, and (c) interactive maps can support children in leveraging their experiential, everyday knowledge about local spaces into their scientific reasoning. In this paper, we report on the results of a design-based research study, in which 4th grade students used a web-based tool called *Local Ground* to collect data, model, and collaboratively analyze what’s underground in the local soil ecology around their school. We examine the affordances of situating children’s data modeling in local spaces and using *Local Ground* as a representational medium. We find that this instructional design supported children in integrating their experiential knowledge to reason about organisms in relation to the environment.

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Introduction

Creating, testing and revising models are central to science (Giere, 1997), reflected in a shifting emphasis within science education research (Lehrer & Schauble, 2015) and recent consensus documents (NRC, 2012). Yet constructing and interpreting representational forms is challenging, with extensive literature documenting children’s difficulties in moving between the world and its symbolized forms. Children’s familiarity with the phenomena in question is an important but often overlooked element of deciphering representations, wherein attaining a “fluid” reading involves bidirectional movement between phenomena and various symbolic forms (Roth, Pozzer-Ardenghi, & Han, 2005; Latour, 1999).

Existing science instruction, especially at the elementary school level, makes this representational interpretation process more challenging in several ways. First, the phenomena of study is often decontextualized (Metz, 2008) and separated from children’s everyday lived experiences (Rivet & Krajcik, 2008), with science instruction seldom engaging children’s local spaces as sites for scientific inquiry. As a result, children’s related knowledge sources are rarely utilized, missing a key opportunity to integrate children’s extensive everyday forms of knowing with more scientific ones (Vygotsky, 1978). Second, children are often presented with “final-form” representations, offering a distorted view of the development and purpose of representational models in science and limiting children’s ability to participate in data transformation processes. Children’s engagement in the modeling process, through which certain aspects of the phenomena are amplified while others are reduced (Latour, 1999), is crucial to both supporting children’s conceptual understanding (Lehrer & Schauble, 2012) and to considering uncertainty of the data (Metz, 2004). Yet in working with increasingly abstracted forms, representations inherently lose the locality and materiality of the phenomena, making it challenging for children to connect these abstracted forms of data to the original phenomena and immediate context.

Our work is based on the following design principles: (a) local spaces can serve as rich resources in children’s science learning, (b) children’s involvement in data modeling can play an integral part in supporting children’s conceptual understanding, and their ability to raise questions about the scientific process and its results, and (c) interactive digital maps can support children in leveraging their experiential, everyday knowledge about local spaces into their reasoning about relationships between organisms and their environment. Within the science education research field, recent generative work has used local spaces as a context for children’s data modeling (Lehrer & Schauble, 2012; Manz, 2012, 2015), with a handful of projects using paper mapping as part of elementary children’s sensemaking. Other projects have used interactive digital maps, often for young people to reflect on social issues in their community (Taylor & Hall, 2013; Van Wart, Tsai & Parikh 2010; Enyedy & Mukhopadhyay, 2007). However, this work has not considered the specific cognitive affordances of spatial representations (i.e. maps) in supporting children's reasoning. Additionally, while some of this work has centered on data modeling within children’s school or neighborhood environments, it hasn’t looked specifically at how children's local knowledge of phenomena is integrated into scientific reasoning. Moreover, most of this work has been done with older students, usually high-school level.

Work in the emerging area of Citizen Science has also investigated how to expand participation (especially local) in scientific inquiry. Much of this work has focused on citizens as data collectors - leveraging their local knowledge and access to contribute to aggregated data sets that support larger-scale analysis and reasoning (Bonney et al., 2009). Other projects have also looked at involving users as data analysts - leveraging their prior knowledge to explain and discuss interesting patterns and trends in the data (Viegas, 2007). While these projects have focused on adult participation, others have investigated involvement of youth and novices (Willett, Aoki, Kumar, Subramanian, & Woodruff, 2010). Yet this work thus far hasn't focused on how and what forms of learning are enabled by these various forms of participation, and whether we need new tools to support these learning outcomes.

In this paper, we report on the results of a design-based research study, in which 4th grade students used a web-based tool called *Local Ground* to collect data, model, visualize and engage in discussion about the local soil ecology around their school. We analyze the affordances of situating children's data modeling in local spaces, and of using this map-based representational medium to support children in integrating their experiential knowledge into their reasoning as they investigate organisms in relation to the environment. Specifically, we explore the following research questions:

(1) In what ways do children reason about organisms in relation to the environment, as they engage in data collection, modeling, and interactive mapping of their local soil ecology?
(2) As they reason, in what ways do children draw on their context-specific knowledge and experiences to support their claims?
(3) How do children use *Local Ground*'s interactive map representation in constructing and communicating these explanations?

We begin by describing the instructional design and context of this research project, followed by our analytical methodology and lastly, our results and implications for future research.

Instructional Design and Context

Our research was conducted in an urban public elementary school (K-5) in the Western United States (40% free or reduced lunch). We worked with one fourth-grade class of 21 students that met twice a week in the Science lab for periods of 45 and 90 minutes. Working closely with the science teacher, we designed a ten-week instructional unit focused on exploring soil ecosystems found on the school grounds. Researchers were involved in all aspects of the design - including curriculum design, developing supporting tools, delivering instruction, designing classroom materials and activities, and leading discussions.

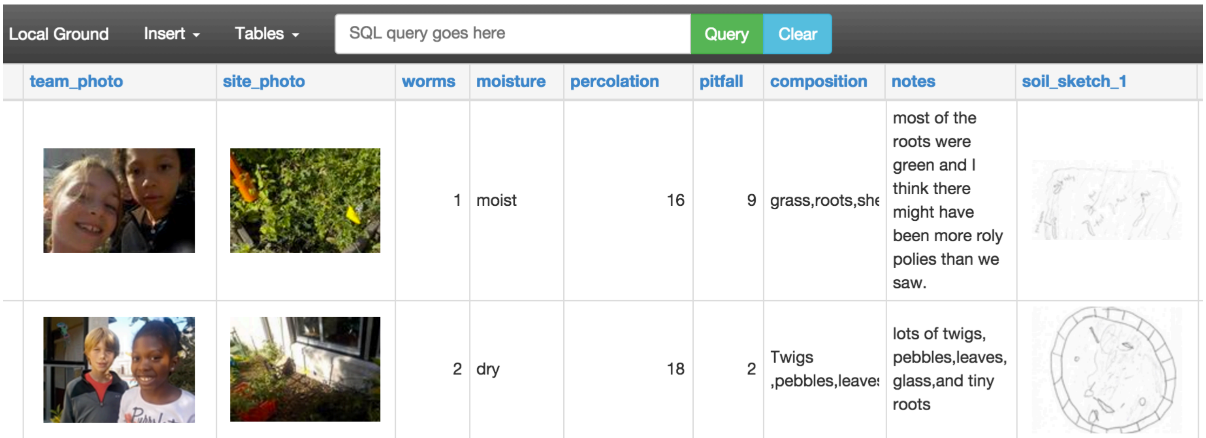
The curriculum was framed around four central questions: (1) What is underfoot? (2) Is it different in different places? (3) How can we find out? and (4) Why might these differences exist? These questions were intended to anchor instruction by problematizing (Dewey, 1929) the physical space, raising questions of method selection and data uncertainty, and encouraging children's explanations of this local ecosystem. Within children's take-up of these what, how, and why questions, we were particularly interested in the children's integration of locally situated knowledge sources into their reasoning, and their use of *Local Ground'*s interactive map interface in constructing and sharing their explanations.

During the first few lessons the researchers elicited the class's ideas about what was underfoot around their school, grouped these ideas into biotic and abiotic "parts" of these underground places, and supported discussion about ways to gather more information about them. Children then worked in pairs to choose sites of interest to explore these "parts" further, selected by the researchers from students' initial ideas to represent a range of distinct microenvironments within the schoolyard. In these groups, children then collected data on both biotic (total invertebrate counts, earthworms, roots) and abiotic (soil moisture, soil compaction, soil color, soil composition) indicators. Children's paper notes took the form of written field notes, sketches, and photographs.

Back in the classroom, each pair worked together to add their data and field notes to *Local Ground*'s spreadsheet interface (Figure 1). The teacher-researcher then used the interactive map interface (Figure 2) to engage children in thinking about similarities and differences at the ten sites, and to reason about why these relationships might exist. Children also physically returned to the ten original sites, to see if any additional site information would be useful in making sense of the relationships (or lack thereof) in their data.

Local Ground

Local Ground is a software tool designed to support children's data collection, modeling, and analysis (Van Wart, Tsai & Parikh 2010). This software allowed the research team to upload and geo-reference the various forms of children's soil data (pictures, audio, video, drawings). It also allowed children to enter and edit their own measurements and notes, and ultimately browse and visualize everyone's data, using either a spreadsheet (Figure 1) or interactive map (Figure 2) interface.



Local Ground | Insert | Tables | SQL query goes here | Query | Clear

team_photo	site_photo	worms	moisture	percolation	pitfall	composition	notes	soil_sketch_1
		1	moist	16	9	grass,roots,she	most of the roots were green and I think there might have been more roly polies than we saw.	
		2	dry	18	2	Twigs ,pebbles,leave	lots of twigs, pebbles,leaves, glass,and tiny roots	

Figure 1: Spreadsheet interface, which students used to enter/edit data into the system.

Figure 2: Interactive map interface, visualizing select variables from students' data collection.

The interactive map allowed children to assign specific symbols to discrete values or ranges for each variable, and to turn on/off any combination of symbols, allowing for the exploration of multivariate relationships across the schoolyard. We mapped four variables – earthworm count, soil moisture, percolation time (in seconds) indicating soil compactness, and pitfall trap count (number of invertebrates sampled). Figure 2 shows two of these indicators, "worm count" and "soil moisture", displayed for each of the ten sites.

Methods

In this paper, we focus on the final three class sessions of the design experiment, which consisted of one day of teacher-led whole classroom discussion and two days of student-led informal presentations. In the teacher-led discussion, children explored relationships between the worm count, soil moisture, soil compaction, and total invertebrate counts, looking at one, two, and then all four variables on the interactive map interface. The teacher-researcher prompted the students by asking them to attend to similarities and differences across variables and sites and to identify "puzzling" relationships. In the student-led presentations, each site group (consisting of two children) explored the interactive map interface together on a laptop, with the same four variables as above, to find "interesting" similarities or differences across sites and reasoning about why these relationships might exist. Then, in a whole-class discussion, each group took turns explaining their findings and related explanations to their peers using a large projected version of the interactive map. Children used this map to explore and discuss one- and multi-variable relationships in their data and to link their observations back to the original data collection sites.

We selected these three lessons because they show how children talked about their data observations at the end of the design experiment, how they leveraged their earlier field and data transformation experiences into this reasoning, and how *Local Ground's* interactive map interface supported this process. Because we wanted to understand how the instructional design, data collection activities, and software mediated student reasoning about the local environment, we created a coding scheme consisting of (1) the different forms of reasoning that children used and (2) the resources children drew on as they reasoned. Using video transcriptions of the last three class sessions, these codes emerged through an iterative process (Miles, Huberman, & Saldaña, 2013) of identifying the types of local, experiential, and map-based evidence that the students marshaled to support their what, why and how reasoning. We started by coding the first lesson together, collaboratively identifying and defining what, why, and how forms of children's reasoning in each turn of child or teacher talk. Using this initial coding scheme, two researchers independently coded the remaining two lessons. We then met to resolve discrepancies and refine the codes further to reach complete agreement.

Next, we coded for the different forms of evidence that children used, working together to identify the different contextually-situated resources children integrated into their reasoning in one lesson and then independently coding the two other lessons, reaching agreement through additional discussion and revisions of these codes (see Table 1). We included the use of the interactive map within these resources, noting indexical utterances (e.g. "here") and gestures involving the map to indicate use. With these forms of reasoning and resources defined and indexed (see Figure 3), we then examined each form of reasoning and the resources together, noting any repeating patterns between these two groups of codes (e.g. children's data collection experiences were often leveraged during how reasoning), and how the interactive map functioned in mediating this process.

Table 1: Coding Definitions and Examples

	Code	**Definition**	**Example**
Forms of Reasoning	What	A simple reporting of data	"They had wet soil and we had dry soil"
	Why	Establishing connections between biotic and abiotic variables (and sites)	"Wouldn't no worms be in compact soil because it would be hard to get into the soil if it's all crammed together?" [connecting worms to soil compaction]
	How	Reflecting on whether the data collection and presentation methods could be used to make a particular claim	"Maybe we didn't dig deep enough to find the worms" [questioning certainty of data sampling techniques]
Resources for Reasoning	Local Data Collection	Referencing specific aspects of the data collection experience	"We both had rollie pollies but theirs were alive and ours were dead" [referring to invertebrate collection experience]
	Local Knowledge	Referencing previous experiences in the schoolyard and local neighborhood	"Those garden beds get watered all of the time"
	Interactive Map	Using the map representation to talk about data points and / or context-specific locations	"I don't think you're right because one of the planters isn't showing here [*pointing to the map*]"
	Prior Knowledge	Reasoning using other forms of knowledge that were applied to a specific contexts but seemed to be generalizable across settings	"Worms can't climb up planters"

Data sources include video recordings of all classroom sessions and children's data collection activities; videos of students' computer screens and corresponding conversations (using the *SnagIt* screen capture tool); students' written and illustrated work; and semi-structured interviews conducted during and after the final class session with select students. In this paper, we report on an analysis of our findings from the final three classroom videos.

Results and Discussion

In this section, we first report on the general forms of children's reasoning that we observed in the three lessons. Next, we discuss the different resources children drew up in their reasoning. We conclude with a vignette illustrating how several different sources of evidence and the *Local Ground* interactive map were used together to support children's reasoning about select variables in relation to the surrounding environment.

Different forms of children's reasoning

Children's reasoning took many forms throughout the three lessons (see Figure 3): describing biotic or abiotic data points (coded as What), locating, considering, and refuting data relationships and explanations (coded as Why), and raising critical questions about methods and measurement issues (coded as How). On multiple occasions, children offered simple descriptions of the data at the ten sites (e.g. Lety: "Our site was dry"). More often, children considered and contested possible explanations about these relationships across several variables and sites. With instructional prompts that encouraged children to look for similarities and differences in the data and explain emergent relationships, they often considered one variable across several sites (e.g. John: "They had wet soil and we had dry soil") and several variables within one site (e.g. Toby: "I noticed Keanu and Lety's site had … um moist soil and one worm and 30 seconds or less for percolation time"). At times, several children even considered multiple variables across several sites (John: "They both had no worms, moist soil, and between 20 and 200 seconds [for percolation time] and … less than 10 invertebrates"). Given the complexity of the data (e.g. multiple biotic and abiotic variables at ten different sites), it is striking how children identified numerous covariate relationships, a challenging undertaking for children and adults alike when using canonical representational forms like scatterplots (Lehrer & Schauble, 2012). Children raised considerations of uncertainty multiple times as well, often in response to puzzling or unexpected relationships in their data. Children posed questions related to sampling errors (e.g. not digging deep enough to find worms, or percolation measurement techniques) and sampling variability (e.g. changing environmental conditions due to the sequencing and timing of data collection).

	L17: Whole Class Discussions							L18: Peer Presentations				L19: Peer Presentations					
elapsed time (minutes):	0-5	5-10	10-15	15-20	20-25	25-30	30-35	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20	20-25	Total
Forms of Reasoning																	
What Reasoning				1		1		3		3	5	5	2	1	1	2	***24***
Why Reasoning	4	1	2	4		3		3	3	2	2	5	3		2	6	***40***
How Reasoning		1		1		1	2				1				1	1	***8***
Resources for Reasoning																	
Local Knowledge	1	2							1		5		2	1			***12***
Local Data Collection	3	2					1		1			5	2				***14***
Interactive Map	1		1	1		6		1	1	3	5	2	1	3	2	6	***33***
Prior Knowledge	0	0	0	0	0	0	1	0	1	1	4	2	0	0	1	0	***10***

Figure 3: Counts of children's scientific reasoning and the resources they draw upon, over time. Note students' frequent use of the interactive map, integrating multiple resources as they reason about schoolyard ecosystem

Resources integrated to support children's reasoning

When looking at the resources children engaged during their reasoning, notable patterns emerge. Children drew from several different sources: experiences stemming from the actual data collection process, local knowledge drawn from daily activities around the school, and prior knowledge not directly related to the local context. In the following paragraphs, we describe the different resources in more detail and the ways in which they were used in children's reasoning.

Children's data collection experience

In most instances, children drew on their data collection experiences to raise questions about methodology and accuracy. Interestingly, these moments occurred in response to confusing or puzzling patterns in their data. For example, as the class reasoned about why worms were unexpectedly found at some of the ten sites and not others, Amir interjected, "Actually, I was going to say...some people didn't find earthworms, they found these other weird worms." Here, Amir is referring to his group's and another group's discovery of a different species of worm during data collection, a finding that was discussed during data collection and recorded in both groups' scientific sketches. In light of Amir's contribution, the class continued to reason about the puzzling relationships, considering that different worms might indeed seek out different kinds of soil.

In a few instances, children also used their first-hand data collection experience to describe specific data points in more detail to better support their own observations or explanations. Elaborated visual or tactile descriptions of the data points were used to describe biotic and abiotic variables in greater detail. For example, in a conversation about different soil moisture levels in two planters – and their relationship to different worm counts – Tomas described the soil at one site as "pretty wet soil and it was shiny", combining both a description of the soil moisture data point and referencing the visual qualities of that original phenomena. Here, students' data analysis reflects a "fluid" movement between the symbolized form and students' memories of their own data collection experiences and those of their peers.

Children's local knowledge about the area

Children's local knowledge was used in more diverse ways to reason about biotic or abiotic variables and the relationship between them, most frequently leveraged in the formation of and argumentation about explanations. This knowledge included human use patterns within the school grounds, as well as "natural" context-specific attributes such as shade and sunlight patterns. Take a discussion about "puzzling" patterns in the class data, emerging from the disconnect between children's expectation that worms prefer soil conditions with more moisture and the children's data on the map reflecting a different pattern:

> Nadia: I think it's weird because, like, worms like wet areas and rain. But we didn't find any worms [in our wet site].
>
> Researcher 2: Do you have any ideas about why?
>
> Nadia: I think that me and Vanessa [interrupted briefly] because... there's a lot of children who play there and they might just stomp...And like the worms will go away. Or maybe the worms are just deep down.

Here, Nadia brings in her local knowledge about children's use of the space during recess to explain why worms might leave the area. She also raises the possibility that worms were actually at her site but the sampling methods didn't accurately capture them.

Children also leveraged their local knowledge of the space to consider additional site attributes influencing biotic and abiotic indicators. In a class discussion highlighting similarities and differences across sites and variables, one child, Eric, notices that two sites located far apart – one in the garden and one in a planter next to a classroom – both had no worms. Eric says, "So I think why me and Tomas didn't find any worms [*points to his site and the other group's site*] ... I think we didn't find any worms because mine was right next to the fence where it gets a lot of sunlight, and Tomas's is just...just sitting out in the sun." Here, he argues that this might be caused by the amount of sunlight each location receives, a variable not originally considered by the class in their data collection and field notes.

Attention to sunlight and shade also emerged in several other children's comments, wherein children attended to shadows created by trees (e.g., Keanu: "Because this one is more in the sunlight and that one's in the shade where the trees are.") and buildings (e.g., Sam: "No, it was covered by the shady part of the building."). By considering these additional site attributes, children were able to reason about soil moisture and worm counts *in relation to* other factors within the original environment. Making a connection between data relationships and the original environment is a conceptually challenging yet crucial step in children's understanding of organisms' "fit" within an ecosystem (Lehrer & Schauble, 2012).

Children's prior knowledge not connected to specific sites

In several instances, children reasoned about relationships in their data using other forms of knowledge that were applied to the specific context, but likely originally developed in a different setting. For example, in trying to explain why worms would likely not climb into the planters (which were surrounded by wide expanses of blacktop), Tomas reasoned: "Well they could...but worms don't really like sunlight. They try...try to stay in the soil so they probably could but wouldn't because it would be really risky." Attending to the plants growing at two sites, one child commented that worms were found at her site and another site because "they [worms] like to munch on leaves...and it would make sense that there are worms there." These reasons tended to be drawn from other experiences, yet brought to bear to reason about the specifics of their local soil ecosystem.

Use of interactive map interface

Throughout the three class sessions, students used the interactive map representation to construct and support their arguments (see Figure 3). In many instances, the children simply used this interface to refer back to individual and aggregate data points. Other times, it functioned like a map, wherein children pointed and gestured toward specific locations in the original space (as in Keanu & Lety pointing to the interactive map interface, saying: "The apple tree's right over here.") Interestingly, at many instances, children used the representation to talk about their biotic and abiotic site data in relation to the specific locations, collapsing the spatial, biotic, and abiotic forms of information together. In these moments, children considered spatially anchored phenomena (like sunlight/shade and schoolchildren's use of these spaces over time) in relation to their abiotic and biotic data points.

On several occasions, the map interface supported students integrating multiple forms of contextually situated knowledge as they explained relationships between organisms and their environment. These moments often occurred during sustained engagement with particular data points and while exploring potential relationships, where explanations were being offered, taken up, and contested by several students. For example, in response to Eric's prediction that the class's data would not show worms in the planter sites "because I don't think worms can climb up planters", Tomas replied:

Tomas:	Uhhh, Eric…I don't think you're right because one of the planters [*site #2*] is not showing right there.
Researcher 1:	What do you mean?
Tomas:	[*Pointing to the two sites on the interactive map]* There are two planters and one of the planters was a bit to the left...like around there... yeah [*in response to Researcher 1 pointing at site #2*]
Researcher 1:	Cool, so you think there should be worms in this spot? [*pointing to site #2*].
Tomas:	I think its…because the planters…mine and Heather's [*pointing to his data and site #2*]…it's because ours is dry and theirs [the other planter group] is really wet. We both had rollie pollies but theirs were alive and ours were dead.
Researcher 1:	Here, right? [*pointing to the two sites*] Ah…so you are saying that you think there are differences in the worms based on soil moisture?
Tomas:	I think it was, it was because we had dry soil and they had pretty wet soil and [the wet soil] was shiny.
Researcher 1:	Ah, and you were both planters, right?

In this example, Tomas argues that differences in worm counts are related to soil moisture levels, not his classmate's mechanistic explanation of worm's climbing abilities. He uses the map-based representation to identify two sites (his and another's groups) that were both in large soil planters. In addition to the worm count data and soil moisture data showing on the interactive map representation, Tomas also recalls and references the invertebrate pitfall trap data collection experience, wherein both groups found rollie pollies (sowbugs) yet his group's sowbugs had all died. In this instance and several others like it, the teacher and students use the interactive map to establish a shared understanding of the data points being discussed (worm count and soil moisture) as well as the original context where the data was gathered (two planters on opposite sides of the schoolyard).

Conclusions

Our findings suggest that situating children's engagement in data design, collection, and analysis within surrounding local spaces and using interactive data maps fostered generative conditions for children to reason about complex biological relationships. Within this design study, children marshaled diverse sources of evidence in reasoning about their data to elaborate descriptions of biotic or abiotic data points, consider and refute often "puzzling" data relationships, and to raise critical questions about methods. Details such as sunlight against a fence, shadows cast by buildings, Kindergarten-favored places to play, and a tree's falling apples were accessible and integrated into children's reasoning, supporting children in sharing and considering their peers' complex explanations. In reasoning this way, children were able to leverage their vast experiential and everyday ways of knowing in grappling with the complexity of a local soil ecosystem.

Local Ground's interactive map appears to be a potentially powerful representational form that warrants further exploration - in both its ability to establish shared references about complex data points and of the physical context from which they come and to facilitate children's "fluid" movement between the world and its symbolized forms. Within science education modeling research, there has been careful attention to children's movement between base and target forms to support knowledge formation. It seems fruitful to explore the potential of this movement across the local contexts of children's daily experiences and within the representational forms themselves, building on the potential affordances of interactive spatial representations to help bridge material and symbolic worlds.

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