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Participatory Digital Mapping, Dynamic Data, and Children's Emergent Science Argumentation About Local Socio-Ecological Systems

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Abstract
Over the last two decades, there has been an increasing focus on spatial technologies in teaching and learning, revealing the potential to support new forms of youth sensemaking across varied settings and modalities. Recent scholarship has shown the possibilities of participatory digital mapping technologies, enabling young people to collect data within community settings and create interactive data-rich maps about complex phenomena and processes that build from their local expertise and inquiries. Yet to date, these technologies and related pedagogies remain less researched within K-5 educational contexts. In this article, we examine the most recent iteration from a multi-year design research project that centered 5th grade students' learning about socio-ecological systems by engaging in participatory digital mapping to study their schoolyard soil ecosystems underfoot. We examine the possibilities of centering digital participatory map making as a basis for modeling and argumentation in elementary science. Analyzing whole class discussion video within the 10-week curriculum, we show how children authored their collective maps in numerous ways, making visible their social and ecological knowledge of the schoolyard, as well as their experiences defining, producing and visualizing qualitative and quantitative data. As part of this broader design-based research project, we find that children were able to reason about complex socio-ecological systems across spatial, temporal, and relational dimensions in inventive ways, often considered out of reach for elementary aged students, while also expanding what could count as data and what ways of knowing were valued within the science classroom. Implications for science education, place-based education, and emerging geospatial technologies are discussed.

Keywords Participatory digital mapping · Elementary science education · Modeling · Argumentation · Ecology · Data · GIS mapping

Introduction

Over the last two decades, there has been an increasing prevalence of spatial technologies within K-12 education, reflecting a broader spatial turn in social sciences (Leander et al., 2010). Sparked in part by the unprecedented accessibility of geospatial data, sensors and software, spatial technologies have enabled young people to access and interact with a wide variety of publicly available digital maps and opened new possibilities for authoring novel geospatial datasets and data visualizations (Haklay et al., 2008). Moreover, these technologies have created new opportunities for educators to challenge and expand where, what and how learning and teaching can unfold within educational spaces.

Participatory digital mapping is a collaborative approach to digital map making that empowers people to create, represent, and share their place-based observations, knowledge, and experiences (Elwood, 2008; Elwood et al., 2011; Tulloch, 2008). In contrast to traditional GIS maps, participatory digital mapping is focused on opening up new channels for authorship and advocacy by centering local expertise and perspectives in question formation, data collection, and collaborative sensemaking (Lanouette & Taylor, 2022). Within educational research, participatory digital mapping has primarily been studied in the context of teenagers and

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young adults, where it has been shown to support critical sensemaking about complex social, political, and historical phenomena central to young people's daily lives (Hall et al., 2020; Headrick Taylor, 2017; Radinsky et al., 2014; Rubel et al., 2017; Mitchell & Elwood, 2012). Such work builds from a long tradition of participatory mapping and community ethnography (see Sieber, 2006 for a review of the literature), centering on the generation of data and maps to enable new forms of authorship, understanding and social action building from youth's local insights, histories, and hopes (Van Wart et al., 2020).

Scholarship in science education has shown how maps and mapmaking can be integral to science disciplinary pursuits and practices. Several studies have focused on the invention and reinvention of paper maps by elementary students (Enyedy, 2010; Lehrer & Pritchard, 2002) and STEM professionals (Hall et al., 2002). With the advent of GIS-based technologies, a wave of work has studied young people's interpretation and meaning making of GIS maps using existing regional and national datasets in middle school, high school and higher education contexts (Loh et al., 1997; Radinsky, 2008, 2020; Radinsky et al., 2010; Roberts & Lyons, 2020; Singer et al., 2008; Switzer et al., 2012). Combined, this work highlights the intuitions young people bring to map building and interpretation, and the integral role maps and mapping can play in science knowledge building.

We aim to contribute to this multidisciplinary scholarship, focusing specifically on elementary school aged children's construction, transformation, and interpretation of participatory digital maps in their modeling and argumentation pursuits as they seek to understand local ecosystems dynamics and processes. This approach contrasts with traditional K-5 science teaching practices in several ways. First, ecology studies often focus on systems in faraway contexts (e.g., Amazon, Arctic), or alternatively, maintain superficial level inquiries into local ecosystems that don't engage the underlying relationships and mechanisms (Metz, 2011; Metz et al., 2019). Second, these common approaches rarely elevate and interweave children's social and ecological expertise of local landscapes into their ecology studies (Davis & Barsoum, 2022; Davis & Schaeffer, 2019; Lim & Barton, 2006; Marin, 2020; Pugh et al., 2019), instead centering textbooks and teachers as the sources of expertise. Lastly, elementary science often provides children with few opportunities for formulating questions, producing and visualizing data, and discussing findings through collaborative modeling practices (Lehrer et al., 2008; Manz, 2012, 2016; Pierson et al., 2017; Schwarz et al., 2022). Given the co-emergent nature of modeling and argumentation practices (Manz, 2015a), these common approaches limit children's ability to engage in meaningful discussion towards individual and collective pursuits. Combined, these common teaching practices make it hard for children to elevate and leverage expertise about local places and data, in turn limiting conceptual understanding of how socio-ecological systems thrive and engagement in knowledge building practices.

In this study, we explore how children ages 10–11 years old engaged in participatory digital mapping as way of exploring a local socio-ecological system (i.e., their schoolyard), documenting and sharing their local knowledge and experiences as they conjectured and contested arguments about what organisms needed to thrive in their schoolyard. Data for this analysis are drawn from a larger multi-year design-based research project (Cobb et al., 2003) that supported late elementary students in 4th and 5th grades learning about local socio-ecological systems in their own schoolyard by authoring collaborative digital maps together (Lanouette, 2022; Lanouette & Van Wart, 2019; Lanouette et al., 2016). *Local Ground*, a web-based participatory digital mapping platform (Van Wart et al., 2020; Van Wart & Parikh, 2013; Van Wart et al., 2010), was central to children's modeling pursuits and practices, supporting data collection, visualization, and discussion. In this analysis, we focus on children's emergent uses of the collaborative participatory digital maps during classroom-based science discussions. Our research questions are: How did children transform their digital maps, weaving together their local expertise of place and data, as they conjectured and contested claims and evidence? What sensemaking about complex socio-ecological systems becomes possible through these emergent transformations?

In the sections that follow, we review related research on teaching and learning about socio-ecological systems, digital mapping technologies, and K-8 science modeling and argumentation. We then detail the research conjectures and study design, where *Local Ground* was integrated into a multi-week elementary science curricular unit. Finally, we describe research methods and findings, and discuss implications for designing and teaching science in local settings and with spatial technologies.

Literature Review

We begin by describing related research on teaching and learning about socio-ecological systems, detailing key approaches, followed by reviewing scholarship on maps and mapping making across multiple disciplines. We argue that participatory digital mapping is a generative method for children's modeling and related argumentation pursuits and practices, particularly in learning about complex systems' inter-relationships in ways that center young people's local and embodied expertise.

Teaching and Learning About Complex Socio-Ecological Systems: Locality, Practices, and Technologies

Children's learning about ecological systems often centers around how systems function, thrive, and decline, focusing on the scarcity, abundance, and distribution of organisms and their relationships within the broader environment across shifting spatial and temporal scales (Eberbach et al., 2021; Forsythe, 2018; Hmelo-Silver & Azevedo, 2006; Lehrer & Schauble, 2017; Manz, 2012). Such sensemaking can present challenges for children, such as considering and coordinating multiple variables across varied temporal and spatial dimensions (Danish, 2014; Enyedy et al., 2015), considering hard to quantify or visualize variables in a complex system, such as sunlight, water flows, and human activities throughout the day and seasons (Manz, 2016) and attuning to the ways specific organisms' needs are met (or not) within smaller scaled niches (Lehrer & Schauble, 2012, 2017).

Learning about complex socio-ecological systems entails further considering how social and ecological systems are entangled with one another across temporal, spatial and organizational scales (Hecht & Nelson, 2021; Lanouette et al, 2024; Learning in Places Collaborative, 2020), elevating interrelationships among species, kinds and behaviors in relation to place, lands and waters (Davis & Schaeffer, 2019; Marin, 2020; Pugh et al., 2019). Teaching about complex socio-ecological systems thus entails attuning to the relationships among human and more than human species, kinds and behaviors, in ways that center the political and ethical dimensions (Kissling & Barton, 2015; McGowan & Bell, 2022).

Several approaches have been pursued to support children's study and learning about complex socio-ecological systems. One approach is to situate studies within places familiar and close to young people. In doing so, children can more easily integrate their understandings of the built, historical and ecological dimensions of their daily lives into their science sensemaking as part of collective inquiries into complex systems functioning and futures (Huffling et al., 2017; Lim & Barton, 2006). Additionally, centering ecology studies around local or immediate ecological systems provides a requisite complexity for science inquiry pursuits, simultaneously elevating both the socio-cultural and political dimensions shaping ecological systems (Carlone, 2016; Davis & Schaeffer, 2019; Frausto Aceves & Morales-Doyle, 2022; Morales-Doyle & Frausto, 2021; Stroupe & Carlone, 2021) and the material complexity sparking the need for emergent science practices such as modeling and argumentation (Manz, 2015b).

Another related approach has centered on supporting children's modeling practices to understand complex systems at local scales (Louca & Zacharia, 2015; Wilkerson-Jerde et al., 2015). Across a range of studies, scholars have found young people can develop strong conceptual understanding by directly creating and juxtaposing multiple data types (e.g., quantitative, qualitative) and data sources (e.g., embodied, first-hand, second-hand data) (Danish et al., 2020; Keifert et al., 2020; Lee et al., 2021). Integral to modeling is creating robust opportunities for collaborative theory-building through discussion, where ideas, evidence and claims can be argued. Manz (2015a, 2015b) notes that epistemic-rich argumentation requires "embedding argumentation in uncertain scientific activity, supporting students to contest both what they know and their means of knowing, building more carefully from students' resources, and attending to the development of epistemic cultures in classrooms" (Manz, 2015a, 2015b, pp 55). In elementary science argumentation research, scholars (González-Howard & McNeill, 2020; Sandoval & Çam, 2011; Sandoval et al., 2019) have noted that argumentation practices evolve and emerge in relation to shared collective goals, with children's work with data first hand as generative for formulating and evaluating the strength of evidence and claims.

Various technologies have been developed to support modeling ecological systems, often centering immediate and local ecological systems. Some approaches involve computer simulations, for instance embedding interactive projections of ecological systems directly into classroom walls (Cober et al., 2012), creating 3-D virtual worlds of nearby local habitats where young people gather data (Dickes et al., 2019; Kamarainen et al., 2015) or generating mixed reality environments where children's playful physical movements become the larger projected model of complex systems (Danish, 2014; Keifert et al., 2020). Other approaches augment how local ecological data are gathered and analyzed. For example, Zimmerman and colleagues have used interactive observation platforms that support collaborative species identification and question asking (Zimmerman & Land, 2014; Zimmerman et al., 2015). Aristeidou et al. (2021) studied how youth used mobile crowdsourcing platforms, such as I Naturalist, to contribute and learn about biodiversity research. Ryokai and Agogino (2013) studied mobile augmented reality to support youth learning about sustainability. Such approaches seek to counter prevalent science teaching practices and technologies, which are designed to be "everywhere and nowhere", far removed from children's local landscapes and the questions, tools, and methods that produce data and related data displays.

Mapmaking as Generative Modality for Collaborative Modeling and Argumentation

Across multiple fields outside of science education, there is a long and established line of scholarship focused on children's creation and interpretation of maps, and their mapping endeavors more broadly (Lanouette & Taylor, 2022). Almost a century ago, Lucy Sprague Mitchell championed an approach to early childhood education that centered on map making, as a means to connect disciplinary studies with the interrelated social, political, and historical dimensions of city life (Mitchell, 1991). Working with large canvas maps, paper and pencil, and clay/ paper mâché map models, she envisioned the making of maps as a core pedagogy essential to understanding the complex interrelationships that constituted children's daily, immediate worlds. Maps and mapmaking have also been key materials and methodologies for adults to understand children's social and physical worlds, such as Hart's (1979) seminal study of young people's map drawing as means to understand their place attachments and histories. Drawing on youth-centered action research methodologies, researchers have also centered maps and mapmaking as a way to elevate children's perspectives and agentic roles in local land use decisions (e.g., Wilson et al., 2019). Combined this work insists on the agency of children as key authors of knowledge production and expression and as intuitive knowers and world makers at multiple scales in their own right (Katz, 2019).

Studies of children's map interpretation and map making are also prevalent in K-8 geography and STEM education contexts as well (Sobel, 1998). Kastens, Liben, and colleagues have studied how elementary aged children use maps to orient themselves and objects in an unfamiliar space, finding that children engage multiple resources to support map orienting and interpretation, while also benefiting from key supports (Kastens & Liben, 2010). Enyedy (2010) studied how 2nd and 3rd grade children reinvented cartographic lines in their study of desert environments, describing how collaborative activity and gesture were integral to emergent cultural conventions that aligned with topographic mapping techniques. Lehrer and Pritchard (2002) detailed 8 and 9 year old children's mapping of their school playground, with the iterative process of mathematicizing the space supporting insights into both mathematical and geographic principles. Lehrer and Pritchard also conjectured the familiarity of the mapping locations (in the schoolyard, at home later with family) contributed to children's ease in creating and refining maps of increasing complexity, as well as establishing a need for further refinement and inventiveness in their map making. Combined this work points to the intuitions and resources children bring to map interpretation and map making, elevating the integral role of gesture, talk, and tasks in children's collaborative sensemaking.

Within science education specifically, there has been scholarship using spatial data and maps to support learning, primarily with middle, high school, and undergraduate students. With the increasing commercialization of GIS technologies in the 1990s, earlier work studied students' use of GIS data maps within inquiry-based software programs. For example, Loh et al. (1997) studied middle and high school students' use of GIS-data maps, within a software platform that aimed to support reflective inquiry through students juxtaposing graphs, maps, and text notes. Radinsky (2008) studied 6th grade students' use of GIS maps within an earth science unit, revealing the integral role of gesture and collaborative discussion in middle school students' causal reasoning and argumentation (Radinsky, 2008; Singer et al., 2008). Kelly and Takao (2002) studied how undergraduate students used GIS spatial data to build written arguments in an oceanography course, focusing on the epistemic complexity of written arguments as students coordinated data and evidence.

Focusing on socio-ecological systems, several researchers have been exploring new waves of GIS map technologies. Reigh et al. (2022) studied middle school students' learning about environmental racism using existing spatial datasets. Students authored and integrated geospatial data visualizations into their writing about how pollution, race, and space intersect at local and global scales. Within a science museum context, Roberts and Lyons (2020) studied how multi-age groups used interactive data-rich maps involving census data to understand social science processes, finding that shifting self-to-data orientations towards the data (e.g., role playing, projection, orientation) supported varied insights (e.g., noting absences, identifying patterns). Such work has parallels within math, social studies, and civics education, where interactive GIS-based maps about youths' city spaces have been integral to interweaving self and society in learning about STEM, history, and statistics (e.g., Enyedy & Mukhopadhyay, 2007; Hall et al., 2020; Kahn & Jiang, 2020; Radinsky, 2020). Working with existing public datasets, this combined research shows the generative role that interactive spatial data maps can play in disciplinary pursuits, as a locus for model building, argumentation, and data sensemaking more broadly.

Participatory Digital Mapping: Local Data, Insights, and Action

Participatory digital mapping builds on GIS-based map technologies described above, but notably supports users in participating more actively in the *process* of mapping. "Participation" in digital mapping can refer to many types of engagements: data gathering (e.g., contributing crowd-sourced data to systems like eBird,[1] iNaturalist,[2] or OpenStreetMap[3]), augmenting existing maps with media and annotations (e.g., Mitchell & Elwood, 2012; Dennis, 2006), engaging in interpretation or storytelling (e.g., creating geospatial visualizations (Rubel et al., 2017), or some combination of these. Moreover, beyond these more instrumental activities involving data construction and interpretation, "participation" also refers to the extent to which participants can incorporate their own knowledge and experiences into the mapping process and exert agency and control over how map-based findings are

[1] https://ebird.org/home

[2] https://www.inaturalist.org/

[3] https://www.openstreetmap.org/#map=4/38.01/-95.84

framed, presented, and shared (Elwood, 2011; Martin, 2003; Van Wart et al., 2020).

In education research, participatory digital mapping has been shown to support situated and civically engaged understandings of math (Rubel et al., 2017), social studies (Elwood & Mitchell 2012; Mitchell & Elwood, 2012; Radinsky et al., 2014), and city planning and environmental activism (Taylor & Hall, 2013; Taylor, 2017; Van Wart et al., 2020). In some studies, young people have produced their own local geospatial datasets (e.g., air quality, food availability, biking and bus transit route data) and used these as the basis for their map making. In other studies, learners have relied on more traditional datasets (e.g., census data, land use datasets, watershed data) in order to understand broader spatial patterns and relationships. Newer technological innovations have also made it easier to integrate qualitative data into digital maps, including photographs, drawings, text notes, and body movements. By augmenting the process of map-making (e.g., first-hand data collection, studying local phenomena and processes) with emerging geospatial technologies, participatory digital mapping offers unique affordances that can center young people's experience and voice in disciplinary and civic pursuits, broaden what ways of knowing can be part of youth learning (e.g., situated, embodied, social) and support understandings complex social, material, and historical phenomena, processes, and problems.

Our study aims to contribute to this multi-disciplinary literature in two ways. First, this study centers the experiences of children in elementary grades. Whereas the majority of participatory digital mapping studies have primarily focused on teenagers and young adults' learning, we wanted to better understand how these tools and processes might support science reasoning in argumentation among younger children. Second, our study examines a particular configuration of "participation" – where learners (1) study a local, familiar context, (2) engage in the end-to-end data modeling (constructing measures and indicators, and then gathering, digitizing visualizing, and analyzing their data), and (3) present and debate their findings collectively (i.e., science argumentation), vis-a-vis their local knowledge and experiences. Given the complexity of socio-ecological systems, we hoped that these forms of participation could create a rich context for helping children consider the embodied, spatial and temporal interrelationships inherent to such systems.

Research Project Design: Conjectures, Curriculum, and Technology

To study the possibilities of participatory digital mapping as a basis for children's science modeling and argumentation, we draw on design-based research methodologies (Cobb et al., 2003), outlining core conjectures (Sandoval, 2014) that determined the tasks, tools, and talk embodied in this multi-year research collaboration with late elementary students and teachers (Lanouette et al., 2016; Lanouette & Wart, 2019; Lanouette, 2022). We conjectured that supporting *children as experts*—of the data they produced and the places they studied—would foster a varied and deep base for argumentation about socio-ecological systems, with *Local Ground*'s flexible interface and layered data integral to children marshaling evidence and making claims (see Fig. 1). Yet what remained unknown was how children would transform their maps in collaborative discussions to reason about what earthworms and other organisms needed to thrive, and how children would leverage these dual forms of expertise in their emerging science argumentation practices. Below, we describe the design of the 10-week curriculum and participatory mapping platform, *Local Ground*, that were integral to the study and refinement of this conjecture.

Locally Situated Modeling Curriculum

To support children learning about complex socio-ecological systems in ways that center young people's expertise and interests, we designed for children's science inquiry to be rooted in their schoolyard. In doing so, we sought to elevate children's local understandings of a familiar place, building from their daily rhythms and routines within the immediate ecological, social and built environment of their schoolyard and neighborhoods (Davis & Barsoum, 2022; Davis & Schaeffer, 2019; Lim & Barton, 2010; Jan Nespor, 2008; Takeuchi, 2021). Central to the curriculum design was engaging children in the question of "Who can thrive here?", to spark curiosity into how living organisms met their needs underground in relation to the above ground social and ecological world of their schoolyard. Across 18 class sessions in the early spring months, a 5th grade class engaged in two cycles of data collection, visualization, and discussion, with *Local Ground* serving as a central hub for data modeling activities and discussion.

Early class sessions focused on brainstorming who and what was underfoot in the schoolyard, identifying potential parts of the underground socio-ecological system to focus on and selecting sampling sites throughout the schoolyard to study potential inter-relationships. Working in pairs, children then brainstormed the kinds of data they wanted to collect and gather at their chosen schoolyard sites to better understand how these varying parts of the socio-ecological system might influence organisms' ability to thrive. Children's data collection activities included counting and sketching any invertebrates they unearthed at their sites, setting pitfall traps to sample invertebrates over several days, describing and measuring the soil composition

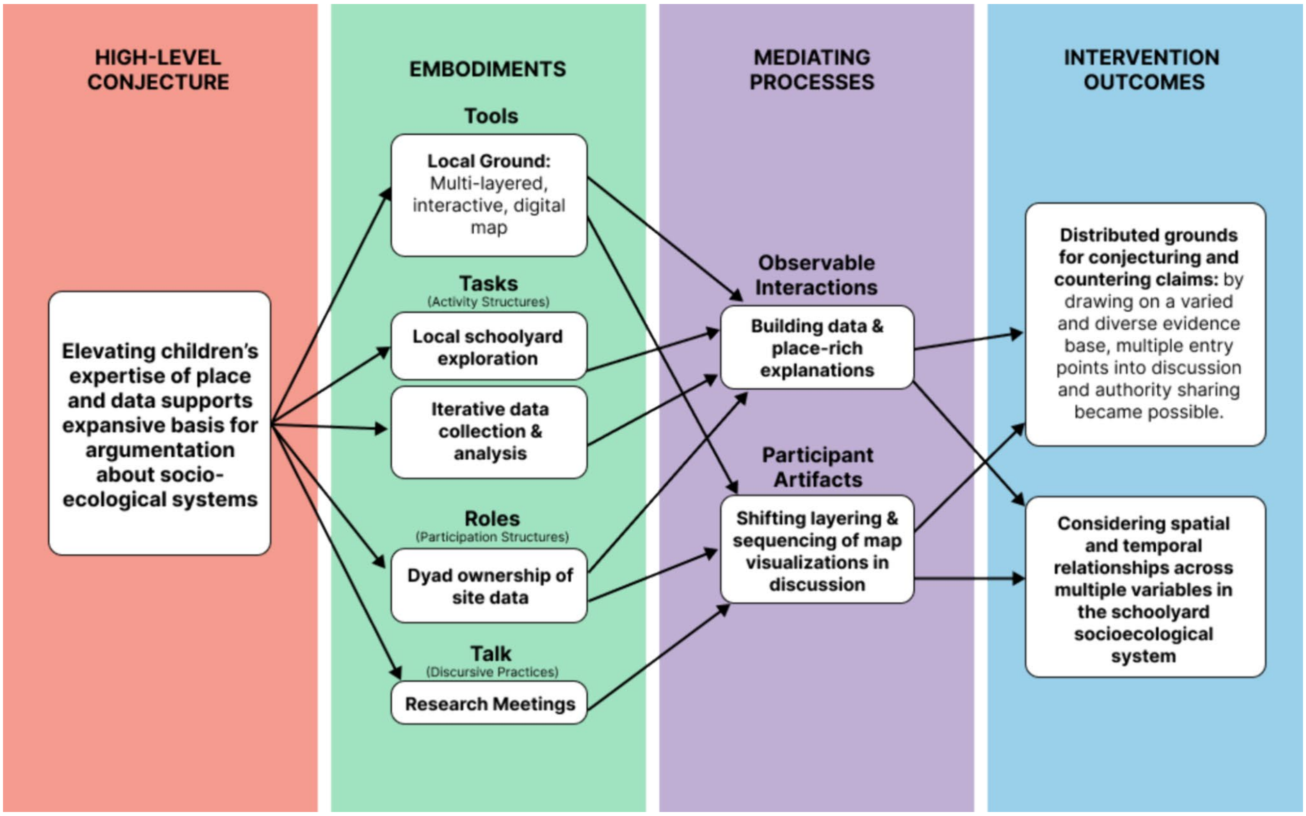


Fig. 1 Conjecture map for research design

(e.g., color, texture, moisture, compactness) and sketching and photographing other parts of the system they thought notable (e.g., foot traffic, noise levels, built structures, children's movements, gardening routines). Back in the classroom, children transcribed, annotated, and explored their aggregated data, using *Local Ground* together in pairs, in small groups and in whole class discussions. Drawing on a research group meeting format (Lehrer et al., 2008; Manz, 2012), children met at the end of each data cycle to consider and critique relationships emergent in the data, authoring and annotating the maps as they shared puzzling or interesting patterns with their peers (see Fig. 2) (see Lanouette, 2022 for more details on the curriculum enactments).

Participatory Digital Mapping Platform, *Local Ground*

Local Ground was developed as a digital data mapping platform to support youth advocacy and activism, allowing young people and civic groups to author and annotate maps documenting their concerns, questions, and hopes (Van Wart et al., 2010; Van Wart & Parikh, 2013; Van Wart et al., 2020). The software allows users to generate and visualize both quantitative data (e.g., geospatial measurements and observations) and qualitative data (notes, comments, drawings, photographs, audio, and video). In this research collaboration, the second and third author designed and implemented *Local Ground* so that students could participate in the entire process of modeling their schoolyard ecosystem – including defining a data protocol, collecting data, uploading and digitizing both quantitative and qualitative data, and creating custom maps. Using the data entry interface, children transcribed and uploaded their schoolyard field notes from the pairs' 24 distinct sampling sites. Children then created custom maps based on emergent questions, by toggling the assigned symbols for the four focal data variables (i.e., earthworms, other invertebrates, soil moisture, soil compaction) (Fig. 3). If children clicked on one of the site locations, more detailed site information (e.g., photographs and sketches of the area, hand-written notes, and other measurements) could be displayed (Fig. 4). These features enabled children to easily juxtapose and move between the symbolic data layers, site level data and the base map (Fig. 5).

Note. This photograph shows the typical arrangement for research meetings, with one pair controlling *Local Ground* and discussing conjectures using the aggregated class data, the lead author recording the main claims and evidence discussed by each pair on large chart paper, and classmates sitting on the rug recording notes, connections and questions on their note sheets.

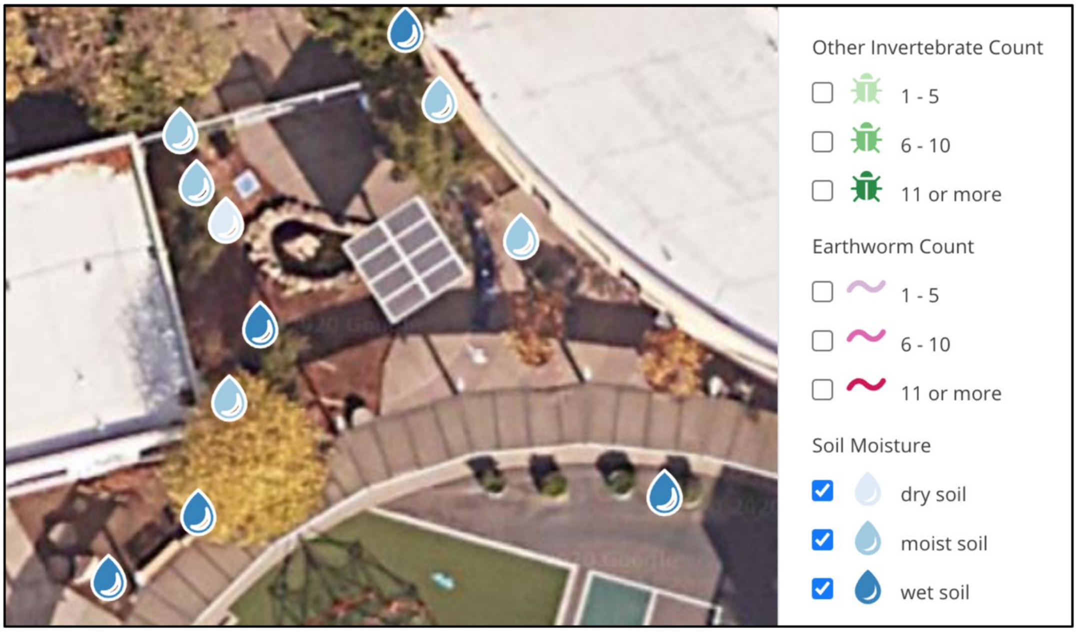
Fig. 2 Typical Research Meeting Set Up

Methods

The multi-year design-based research study was conducted in a racially, linguistically, and economically diverse public elementary school (K-5) in the Western United States. In this most recent iteration, the first author served as the lead designer, teacher, and researcher, working closely with two teachers—Ms. K, who had over ten years of science teaching experience and Ms. Z, a 5th grade homeroom teacher who had 15 years of late elementary teaching experience. The second and third authors led the iterative design and redesign of *Local Ground* as well as advising on user interface and data structure decisions. The 5th grade class consisted of 27 students, reflecting similar demographics of the larger school community. All students participated in general activities, with 24 children consenting to be part of the research study. (All names and places are pseudonyms).

Data Sources

Data sources specific to this analysis include (a) two video recordings of whole-class discussion, including back of the classroom angle capturing presenting pairs' use of the digital map and a front facing, wide angle capturing six focal pairs' and classmates' activity, (b) screen capture videos (Snagit) from the six focal pairs' laptop computer as they adapted the digital map, and (c) audio recordings from the front and back of the classroom. We also analyzed paper artifacts, in the form of the teacher's annotated charts and students' question and comment sheets, along with researcher field notes drafted by the first author and a research assistant.



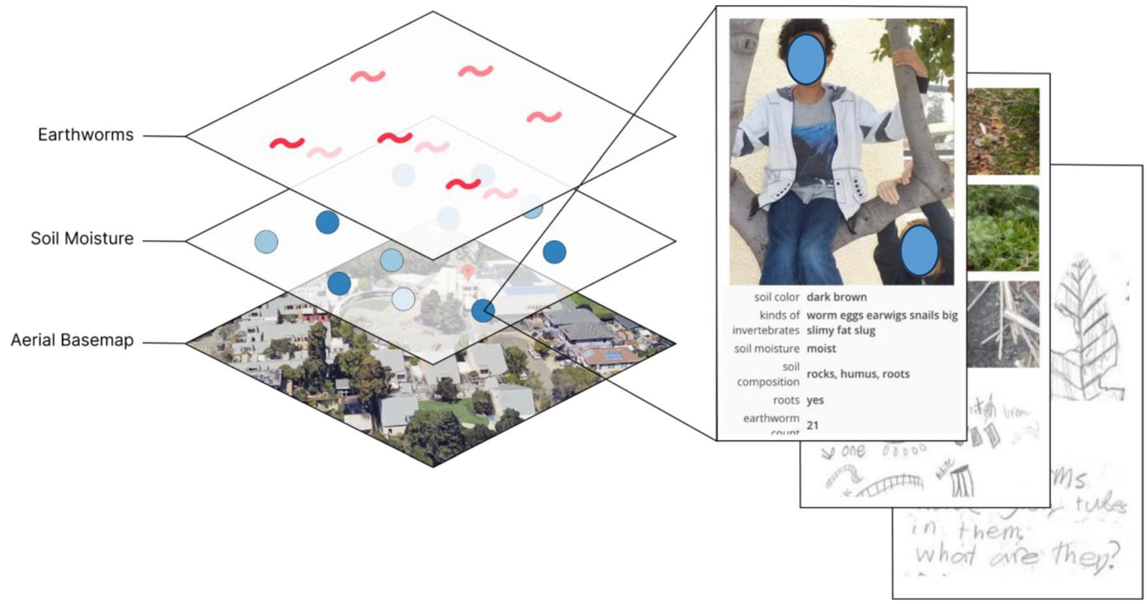
Note. This child's map shows the "soil moisture" dimension, overlaid on an aerial map of the schoolyard, and focusing on one small section of the schoolyard.

Fig. 3 Symbolic data layer

Fig. 4 Site-level data

Theoretical and Methodological Frameworks

To study the interplay of children's emergent *Local Ground* use and their collective sensemaking about complex socio-ecological systems, we draw on Saxe's form-function theorization conceptualizing cognition as movement and process (Saxe, 2012; Saxe & Esmonde, 2005). This framework focuses on the dynamic ways in which interlocutors engage in collective practices, where cultural *forms* come to serve specific *functions* as they conceptualize and accomplish emergent goals together



Note. Local Ground allows users to interact with the different data layers, data types, and data formats all at once, including the aerial base maps, site level data and symbolic data layers.

Fig. 5 Base map, symbolic data, and site-level data layers all together

(see Radke et al., 2022 for recent extensions of this methodology). 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). We draw on this theoretical and methodological approach to illuminate and study the emergent ways *Local Ground* was authored and annotated by children as they encountered problems related to constructing, considering, and critiquing varied claims and evidence about socio-ecological systems.

Analysis

To address our research questions, we focused on emergent *form-function* relationships as children transformed the interactive maps in whole class presentations and discussions. The first author, working with two undergraduate research assistants, engaged in iterative waves of video analysis using interaction analysis methodologies (Jordan & Henderson, 1995), focusing on multi-modal blends of technology uses and sensemaking (Sakr et al., 2016). We first time-indexed and content-logged the relevant whole group and screen capture video (Derry et al., 2010; Saldaña, 2021), demarking activity according to each pair's presentation. Within each of these presentations, we wrote memos and timestamped representative episodes where children raised conceptual ideas about socio-ecological systems, such as reasoning about organisms' needs being met in certain niches (Lehrer & Schauble, 2012) and considering multiple scales of the system concurrently, such as temporal, spatial, and relational (Learning in Places, 2020; Pugh et al., 2019).

Next, within these ten pair-led presentations, we focused on children's emergent goals in their science discussion, focusing on how varied forms were assembled and transformed by children to serve particular functions. Similar to Radke et al. (2022), we define *forms* as "assemblages of linguistic, physical, and material constructions that constituted conceptual themes that took on meaning to accomplish some goal" (Radke et al., 2022, pg. 207). Given our focus on how children leveraged *Local Ground* in their modeling and science argumentation pursuits, we focused on multi-modal forms of sensemaking such as gesture, talk, and digital material reconfigurations of their map layers and other material objects (additional charts, equipment). For *functions*, we focused on what was accomplished in terms of science argumentation (e.g., conjecture, contest, and corroborate claims and evidence) and socio-ecological sensemaking (e.g., considering new variables, looking at inter-relationships across multiple scales). We selected one student-led discussion for more detailed analysis, as it was reflective of broader form-function relationships that emerged across multiple children's presentations.

Findings

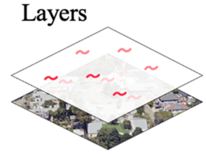
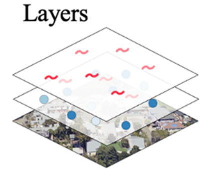
In this section, we present one pair's presentation, an illustrative case of children's emergent goals in discussion shaping shifting form-function relationships as they conjectured and contested what earthworms and other invertebrates need to thrive in their schoolyard. In the vignette below, children's transformations of *Local Ground* support not only conceptual insights into complex interrelationships within the socio-ecological system but also help the children draw upon their schoolyard and data expertise within the modeled systems. The children then marshal this widened base of evidence to explore divergent explanations of how their schoolyard socio-ecological system functioned and flourished (see Appendix A, Table 2 for a summary of emergent goals and form/ function relationships across all ten presentations).

Lena and Max's Earthworm and Shade Conjecture

At the beginning of their presentation, Lena and Max put forth a complex conjecture: high earthworm counts occur in locations with moist soil, roots, *and* shade. This last variable, shade, had yet to be considered by the class and is challenging for children and scientists alike to quantify and visualize into their reasoning about ecological systems. As the discussion progressed, children conjectured and contested this multivariate relationship across spatial and temporal scales, transforming their maps to make visible their local expertise about seasonal changes in sunlight and plant regrowth and children's schoolyard movements across space and time, as well as their understanding of where and how the data was produced.

The case presentation of this class discussion is divided into three phases: (1) an opening conjecture by Lena and Max where they explore the spatial distribution of the earthworm counts across the

Table 1 Emergent form-function relationships supporting argumentation and socio-ecological sensemaking

Claims	*Evidence*	*Forms*	*Functions*
1. Lena & Max's opening conjecture: Earthworms need moist soil, roots, and shade[4]			
Earthworms thrive when there is moist soil, roots and shade!	- Schoolyard knowledge: sunlight across multiple sites - Spatial display of aggregated earthworm data	- Base Map Gesture - Symbolic Data Layers 	*Invent* temporally and spatially transient variable *Conjecture* multivariate conditions earthworms need to thrive
2. Marcel's counterclaim: There isn't really shade there now[5]			
Lena and Max's sampling site is not actually shady this time of year	- Schoolyard knowledge: sunlight, shade, and plant growth across seasons and in a particular spot - Aerial base map	- Base Map Gesture 	*Contest* presence of specific variable and its impact on earthworms at select sampling sites
3. Ellis' counterclaim: My site tells a different story[6]			
Those four variables don't always result in high earthworm counts – look at my site!	- Schoolyard knowledge: walking pathways and building footprints - Shifting spatial display of earthworm, other invertebrate, and soil moisture variables - Photo of the field site, notes, and sketches	- Base Map - Site-Level Data - Symbolic Data Layers 	*Contest* causal relationship among earthworms, soil conditions, and sunlight, by contrasting two sampling sites

schoolyard, using gesture and *Local Ground*'s symbolic data layers to show the presence of shade in relation to the spatial distributions of earthworms, (2) a contestation by Marcel refuting shade being the likely variable in Lena and Max's sampling area given the time of year, with both children drawing on their schoolyard knowledge of children's activities, specific plants growing in the area and seasonal shifts in foliage to verify and contest the prevalence and relevance of this new variable, and (3) a second contestation by Ellis, using the symbolic layer and site-level data to compare similarities and differences across multiple variables at two locations, one of which was his (see Table 1 for an overview).

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 and Max's emergent goal was to show how these three variables supported higher earthworm counts (see Fig. 6).

"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, Figure a*). There is lots of shade because there are lots of trees."

"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, Figure b*) and there is not a single eleven or more worms (*pointing to the map legend on right side of map, indicated by the pink 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 looooot to do with worms."

Lena and Max then change the map location again, to show earthworm counts at their second sampling site near the track (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!"

Note. Screen captures and annotations from Lena and Max's laptop showing assemblages of map layers, talk and gesture they two construct to conjecture that shade is a new and important variable to consider.

Fig. 6 Lena and Max's opening conjecture: assemblages of talk, map layers, and gesture

Analysis To accomplish their emergent goal—conjecturing a new multivariate relationship shaping schoolyard life, Lena and Max assemble the base map layer, the symbolic data layer, gesture, and talk together to accomplish the functions of making a spatial data argument and making visible their local ecological expertise. *Transformations of their digital maps* (RQ1) included the pair juxtaposing the base map and symbolic data layers together, layering gestures on top of shifting scales of the map to argue that earthworms prefer not only moist soil and roots but also shade at three different locations in the schoolyard. To do this, they change the map's scale and location frequently, shifting from the school garden to the pond to the sports fields by zooming and moving the base map layer (Figure a, b, and c). In terms of s*ensemaking about socio-ecological systems* (RQ2), Lena and Max layer together their expertise of the schoolyard (e.g., sunlight and shade patterns across the day shown through gesture across the map, locations of trees and sizes of their canopies, sunlight drying out soil) and their expertise of the data derived from a particular site (e.g., site selection and sampling practices, specific attributes of the sampling site) using the symbolic data map layer (e.g., earthworm counts at all 24 sampling sites). In the process, the two conceptualize, conjecture and make visible to their peers a multivariate spatial and temporal relationship. By drawing from a wide base of evidentiary support and from their own local knowledge, Lena and Max are able to consider and explain how sub-niches within the broader schoolyard support life differently—a key idea in ecology.

Marcel's Counterclaim: There Isn't Really Shade There Now

Lena and Max then open up the discussion for questions and comments, with Ms. K, the K-5 science teacher, interjecting that another student, 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 a lot of sun there (*pointing to the area where Lena referenced earlier)* 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 then details her sampling site in more detail, using extended gestures to clarify her site's location, showing children's daily foot traffic patterns in the area by marching her fingers (Fig. 7a) and depicting shade cast by the decaying lavender bush at her site using outstretched arms and draped fingers (Fig. 7b).

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 Fig. 8a). Max simultaneously moves back to the laptop, zooming in the map to show their site's location and plants in closer view (see Fig. 8b).

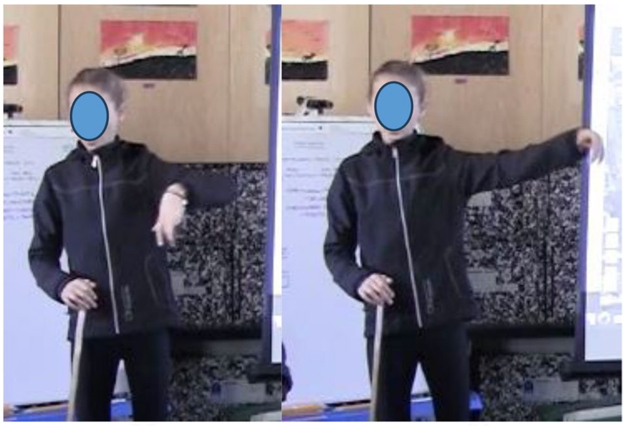
Analysis Here, two emergent goals are pursued—by Marcel to contest that shade is actually present at the pairs' sampling site and by Lena and Max to counter argue shade as both prevalent and relevant. Related to *map transformations* (RQ1), Marcel first transforms the base map layer through gesture and talk to ground his local ecological expertise of how the trees are growing and changing in the schoolyard across multiple time scales, when he points towards the map and says, "So right now, the cherry tree is really bare (*gesturing towards the specific location*)." Lena and Max then work in tandem to counter this counterclaim. Lena first uses extended gestures in front of the map, to make visible children's daily walking pathways and the shade cast by a particular plant, weaving together social and ecological expertise of the schoolyard. Lena and Max then work in tandem, changing the using the base map layer's scale to verify the presence of shade, drawing on the photographic aspects of the map to garner more evidence for this claim.

Considered all together, the base map functions as an anchor for all three children marshaling specific local knowledge from their daily rhythms and routines in the schoolyards, including social (e.g., children's daily walking pathways) and ecological routines (e.g., annual foliage emergence of two different plant species). This supported *socio-ecological sensemaking in several ways* (RQ2). By shifting both the scale and the location of the base map, Marcel, Lena, and Max could debate the timing and location of shade in particular areas and children's walking routes, in relation to how the changing light might influence the soil ecosystem underground. These shifting assemblages of *Local Ground's* layers, gesture, and talk support conceptual understandings about how earthworms' needs are being met within a particular niche environment and argumentative functions of building claims from varied ways of knowing the schoolyard (aggregated data, social and ecological rhythms and routines).

Ellis's Counterclaim: My Site and My Data Tell a Different Story

Lena and Max then call on another child, Ellis, who uses his sampling site data in the garden to also refute Lena and Max's initial conjecture. 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, and selecting the relevant symbolic data to include soil moisture and earthworm counts (Fig. 9).

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?" Ellis clicks on his particular site to reveal the site-level data, showing his sketches and text notes about roots as well as their site photograph. 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. As the recess bell rings, Ellis replies he doesn't



(a) (b)

Note. Screenshots of Lena's gestures, as she shows her sampling site from an on-the-ground perspective. She first depicts (7a) children's movement through the space using marching finger motions. She then depicts (7b) the shade cast by the nearby bush by extending her arm, all part of her contesting that there is actually shade in her sampling location.

Fig. 7 Lena showing her local knowledge of children's walking pathways and shadows cast by plants and buildings

have a decaying lavender bush at his location and the discussion abruptly stops.

Analysis Ellis takes up Marcel's earlier goal—to contest the importance of shade in creating generative conditions for earthworms to thrive. Initially, Ellis draws on his first-person experiences collecting data, the symbolic data layer, and the base map layer to contest Lena and Max's conjecture. He *transforms the map* (RQ1) by changing the scale, location, and selected symbolic data maps, using qualitative and quantitative data from his and his partners' own site and Lena and Max's site. He holds four variables constant across the two sites, comparing soil moisture, shade, earthworm counts, and roots to note an important difference between his site and Lena and Max's site in terms of earthworm counts. This supports *reasoning about socio-ecological systems (RQ2)* in ways that consider multiple interrelationships across spatial scales. This type of work with data, comparing across multiple variables and locations, has been shown to be challenging for children working with canonical graphs (Kuhn & Dean, 2005) yet important for understanding ecosystem dynamics and processes (Lehrer & Schauble, 2012). Additionally, multiple data types, from numerical (earthworm counts), categorical (soil moisture), text (written descriptions of roots), to gestured spatial areas of shade, could all be marshaled and made visible in countering Lena and Max initial claim.

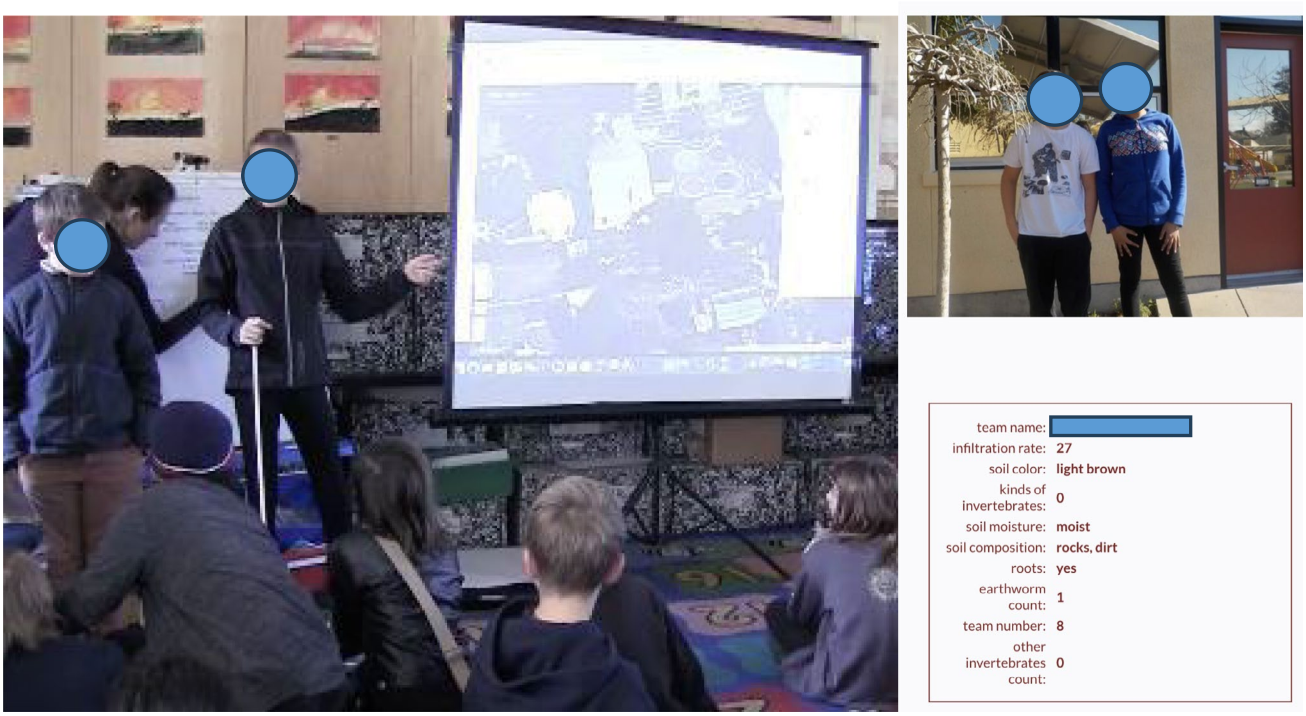
Summary of Case

Across this series of exchanges, children conjectured and contested complex inter-relationships within their schoolyards' ecologies and within their collective dataset. By configuring *Local Ground*'s many layers to explore spatial distributions of data, juxtaposing multiple variables simultaneously, drilling down to their site-level data, and sharing their local expertise, children were able to engage in a rich analysis of the social and environmental rhythms and routines shaping schoolyard life underfoot. This involved considering and coordinating multiple types of evidence across spatial and temporal scales, including children's measurements and observations collected from their field work (e.g., water levels in the soil, earthworm tallies, roots), children's local social expertise (e.g., where children walk, run and play) and ecological expertise (e.g., how sunlight moves across the schoolyard, where different species of plants grow, tree's timing of annual leave regrowth). In turn, this made possible not only a more robust pairing of claims and evidence but also widening the

(a) (b)

Note. Lena and Max's shift Lena points to her sampling site (8a), referencing her everyday knowledge that shade is provided by nearby plants while (8b) Max moves to the laptop computer that controls the map, using it to zoom into their exact site.

Fig. 8 Lena and Max's shifting form/ function relationships



Note. Ellis, crouching on the ground in the near left corner of the photo wearing the blue hat. He uses the laptop to pan and zoom the map to his garden site, changes the symbolic data layers, and opens up the site level data showing text notes and photographs. Lena and Max stand near Ellis, asking further questions about plants and soil quality at his site.

Fig. 9 Shifting map forms, blending schoolyard knowledge, and comparing variables

evidentiary grounds that children could marshal when arguing their points.

Discussion and Implications

In this analysis, we set out to understand not only how children used *Local Ground's* varying data types and layers as they engaged in science argumentation but also what sensemaking about socio-ecological systems became possible. We explored these questions within a design-based research collaboration that sought to help children more easily interweave their knowledge, experiences, and intuitions into their data modeling and socio-ecological reasoning. From our analysis of pair-led discussions, we highlight four contributions of this study to understandings of data modeling, science argumentation, and scientific sensemaking among elementary school children.

Building on Children's Local Expertise to Understand Socio-Ecological Systems

First, our findings highlight the richness of children's local expertise, as a powerful resource not only in reasoning about complex socio-ecological systems but also in shifting what forms of knowledge can be brought to bear in collective science sensemaking. Across the class discussions that we analyzed, children engaged in a seamless blending of their situated, local expertise (e.g., knowledge of changing foliage patterns with the seasons, daily shifts in sunlight and shade, children's daily movements at recess) with multivariate data as they conjectured about ecological relationships. Moreover, children's recollections of their data collection process and their knowledge of the schoolyard were not only positioned as valid and important ways of contributing to the discussion, but also enabled the class to identify new variables that were not originally considered (e.g., shade, foot traffic, seasonal flooding). Local and experiential knowledge is often sidelined in traditional K-8 science and data science – particularly children's embodied knowledge of their "lived landscapes" (Seyer-Ochi, 2006) within their schoolyards, home, and neighborhood communities (Davis & Barsoum, 2022; Lim & Barton, 2010; Takeuchi, 2021). By elevating children's local expertise, this design research project opened up wider entry points into science argumentation, and enabled children to make more nuanced and complex socio-ecological arguments drawing on their local understandings of social and ecological systems.

Data Technologies that Elevate Multiplicity and Authorship in Data Visualizations

Our analysis also highlights the importance of providing young people with tools and resources that support a wide range of data—both qualitative and quantitative—and the ability to readily configure these data forms to advance particular arguments. We focused on three capabilities of *Local Ground*: (1) *symbolic data layers*—for displaying spatial distributions and examining multivariate relationships, (2) *site-level data*—for revisiting scientific sketches, text notes, and photographs (i.e., qualitative data) to verify measurements and explore contextual features (e.g., humus from a decaying lavender bush), and (3) the *aerial base map*—for grounding discussions of schoolyard characteristics (e.g., sunny and shady areas over time, areas of high foot traffic). Taken together, these features enabled children to incorporate many forms of evidence into their arguments, which in turn allowed them to consider multivariate relationships across time and space, notice niche environments within a broader area that uniquely support particular species, and attend to variation and distribution in their aggregated data (Lehrer & Schauble, 2012). Also important was the ease with which children were able to *move between* these different knowledge representations: during a single discussion, children easily reconfigured the map, on the fly, in order to craft evidence-based conjectures around what might constitute the ideal earthworm habitat. Other discussion dove deep into the site level data to understand what several hard-shelled invertebrates might need. We argue that having a familiar, central data representation (the aerial map of the school), a broad base of data forms (both qualitative and quantitative), and the ability to visualize and move between different views of the data (both at the site-level and in aggregate) can foster rich, inclusive scientific discussions that incorporate many different forms of knowledge and insight. Such work contributes to seminal research in modeling (Danish, 2014; DeLiema et al., 2019; Keifert et al., 2020; Schwarz et al., 2022) that has shown the conceptual and epistemic possibilities when physical and representational movement across scales and systems is supported. We extend this direction by focusing on what is feasible when children's local social and ecological expertise is integral to these collaboratively modeled worlds.

Synergies Between Mapping and Data Modeling

Thirdly, this work brings together synergistic but often separate lines of research—data modeling and participatory mapping—in order to demonstrate how each can support the other in K-5 science education. In data modeling research within science education, a growing body of work has studied hybrid, computational, and embodied forms of K-12 science modeling (e.g., Enyedy et al., 2015; Keifert et al., 2020; Wilkerson-Jerde et al., 2015), showing the power and possibilities of data modeling using embodied, representational and playful modalities. We add to this work by showing what is possible for data modeling when children's immediate social and ecological worlds become part of the systems and dynamics they are modeling. Here, playground routines, tree growth, and sunlight patterns were integral and inseparable to children's understanding of what earthworms need to thrive, in ways that can be harder (or impossible) in simulated systems.

This study also contributes to the participatory mapping literature by providing a detailed account of how geospatial data modeling can become a rich pathway for participation in local scientific sensemaking. Participatory mapping is often conceptualized as a way to bridge local knowledge with more quantitative, aggregate understandings of place—where "the community" contributes local knowledge in the form of qualitative data, and institutional actors (e.g., scientists, city planners) contribute geospatial indicators and metrics (see Seiber, 2006). This configuration can be a powerful way to share knowledge and build richer understandings of place, and our study shows what is possible when children participate in a broad range of data practices. Specifically, by engaging children in data modeling and quantitative reasoning as well as positioning children as local experts of their schoolyard, they were able to challenge quantitative assertions that did not resonate with their local knowledge experiences (e.g., the role of shade, children's foot traffic), propose their own ecological theories involving multivariate relationships (e.g., "worms like moist soil, shade, and roots"), engage in evidence-based debates with their classmates where knowledge was distributed, and collectively generate a rich model of their schoolyard ecosystem. While children did not engage in the politics of knowledge representation—a central tenet in many participatory mapping efforts (e.g., using a map to effect change or make more inclusive decisions, as described in Elwood, 2011)—children's participation in mapping and modeling allowed them to not only develop their quantitative literacies (powerful epistemic forms) but also leverage their local knowledge and experiences of the schoolyard.

Methodological Approaches and Insights

In this article, we also seek to develop a methodological approach to studying the interplay among children's emerging disciplinary practices, participatory technologies, and children's science sensemaking. With our focus on children's emergent goals as they conjectured and contested claims and evidence, Saxe's form/function framework (Saxe, 2012) helps make visible how science discourse practices, digital and material tools and children's science understandings co-develop within K-5 classroom communities. This framework also illuminates children's inventiveness and ingenuity in science argumentation, revealing capabilities often obscured within curricular, pedagogical and technological approaches common to elementary science. Similar to Radke et al. (2022), the framework also helps us elevate young peoples' in situ, emergent, and collaborative engagements in disciplinary practices, in ways that can expand what disciplinary ways of being can sound and look like.

Implication for Practice and Next Directions

In terms of pedagogy and design, we see several implications for science education as well as the design of data-rich technologies. First, given the emphasis on data and modeling practices with NGSS, consensus documents (NRC, 2012), and Science and Technology Studies literature, this study reveals the importance of thinking carefully about the types of data children are supported in producing as well as the forms of participation they can partake in with these data. Existing studies of science classrooms point to the limited data types and data tools science educators currently use (Rosenberg et al., 2022), with small sets of quantitative data and traditional spreadsheets and graphs commonplace. Yet existing scholarship shows the possibility and power of children's science reasoning when data types such as sketches, body movements, photographs, and other qualitative data are supported in computationally-rich platforms (Keifert et al., 2020; Taylor & Hall, 2013; Wilkerson-Jerde et al., 2015). In our findings, we show how varied data sources and flexible data formats were critical in helping students theorize about their socio-ecological environments by providing a context for fuller expression of observations, insights, and perspectives from the daily rhythms and social routines (Nespor, 2010). Especially as we think about younger learners in the elementary grades, we think designing data-rich activities that make visible, useful and usable a wide range of data and ways of knowing local places across adaptable and shareable formats is especially important for affirming children's dignity and insights within disciplinary pursuits.

Second, as educators and researchers seek to provide more holistic, equitable and meaningful modeling opportunities for youth (Schwarz et al., 2022), we see possibility in continuing to explore mapping and modeling in local places, particularly for elevating children's embodied resources. With mapping as the basis for all modeling activity, children's understanding of the social and ecological world was not lost but instead was made central to building and interpreting their data modeled schoolyard. For example, through gestures across and in front of their maps, children could readily express their local, experiential knowledge of peers, plants, sunlight and rainfall, as part of their larger discussions of visible and invisible inter-relationships within mapped systems (Enyedy, 2010; Radinsky et al., 2014). Within the interactive data maps themselves, children could also make visible localized experiences and observations, such as returning to their sketches of invertebrates when discussing aggregated soil moisture measurements across all 24 sampling sites. Whether supported by a digital mapping platform such at *Local Ground*, or using other (non-digital) means, we argue that drawing from participatory mapping pedagogies, such as centering local inquiries and expertise and making maps collectively and being open to multiple "data" types, can be important ways of centering children's fuller selves in their modeling pursuits.

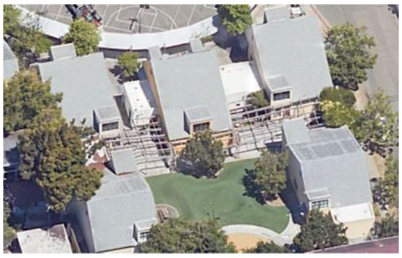
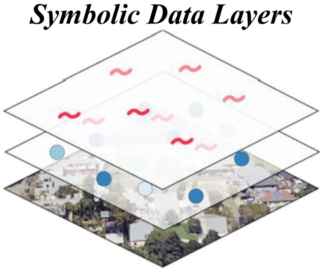
Conclusions

Given ongoing attention to designing and studying meaningful and equitable engagement in science disciplinary practices in elementary settings (NRC, 2012; National Academies, 2024; Schwarz et al., 2022), this work points to potential of designing science modeling opportunities in ways that expand what counts as data, what counts as evidence, and what forms of sensemaking can be leveraged in understanding complex socio-ecological systems central to children's daily lives. As pushes for data literacy and data modeling ("data science") permeate K-8 science education and broader educational contexts, it is important to continue designing in ways that value children's expertise and expand what science modeling can be.

Appendix

Appendix A: Summary of emergent form/function relationships across ten presentations

Table 2 Emergent form-function relationships supporting sense making about socio-ecological systems

Forms (assemblages of the digital map, gesture and talk)	**Serving Emergent Functions (in socio-ecological sensemaking)**
Aerial Base Map 	*Show multi-modal schoolyard knowledge spanning across days, months and years* - human activity (e.g., footsteps, children's play routines) - more-than-human activity (e.g., bees' preferred gathering - spot) - other environmental dimensions (e.g., sunlight, shade, water) *Verify sub-niche areas within the schoolyard* - define micro-climates by zooming into particular smaller areas - use photographic base to gain additional details of the system
Site-Level Data  	*Clarify categorization of multiple species* - refer to sketches to clarify or refute invertebrate or plant species morphology (size, shape, color) *Verify multi-species tallies, measurements and anecdotal notes* - refer to text notes to verify original numeric recordings, in contrast to range of counts (1-5) shown in the symbolic data layer *Explore sub-niche areas with the schoolyard in greater detail* - using their photographs to look more closely or share additional details about the sampling sites' attributes (social, ecological)
Symbolic Data Layers 	*Display spatial distributions of select variables* - across varying scales and data types (e.g., earthworm counts in playground and garden, soil compaction across the entire schoolyard) *Coordinate multivariate (two, three or four variables) simultaneously* - examining causal and correlational interrelationships (e.g., considering interrelationships among earthworms, other invertebrate counts and soil compaction)

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Data Availability Data is restricted due to human subjects permissions.

Declarations

Ethics Approval Approval to conduct the research was received from the relevant university institutional review board, and ethical guidelines were followed in conducting this research. Informed consent was obtained from all participants, including children, their families, and their teachers.

Conflict of Interest The authors declare no competing interests.

References

Aristeidou, M., Herodotou, C., Ballard, H. L., Higgins, L., Johnson, R. F., Miller, A. E., Young, A. N., & Robinson, L. D. (2021). How do young community and citizen science volunteers support scientific research on biodiversity? The Case of iNaturalist. *Diversity, 13*(318), 1–16.

Carlone, H. (2016). Field ecology: A modest, but imaginable, contestation of neoliberal science education. *Mind Culture and Activity, 23*(3), 199–211. https://doi.org/10.1080/10749039.2016.1194433

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13.

Cober, R., Fong, C., Gnoli, A., Silva, B. L., Lui, M., Madeira, C., McCann, C., Moher, T., Slotta, J., & Tissenbaum, M. (2012). Embedded Phenomena for Knowledge Communities: Supporting complex practices and interactions within a community of inquiry in the elementary science classroom. *Proceedings of the Tenth International Conference of the Learning Sciences, 2*, 64–71.

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences, 23*(2), 100–148. https://doi.org/10.1080/10508406.2013.856793

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: A sociocultural framework for embodied cognition. *International Journal of Computer-Supported Collaborative Learning*, 49–87. https://doi.org/10.1007/s11412-020-09317-3

Davis, N. R., & Barsoum, R. (2022). Children as design visionaries, learners, and socio-political wayfinders: Mapping the layers, hierarchies, and rhythms of a school community. *Occasional Paper Series*, *2022*(48), 62–78. https://doi.org/10.58295/2375-3668.1455

Davis, N. R., & Schaeffer, J. (2019). Troubling troubled waters in elementary science education: Politics, ethics & black children's conceptions of water [justice] in the era of flint. *Cognition and Instruction, 37*(3), 367–389. https://doi.org/10.1080/07370008.2019.1624548

DeLiema, D., Enyedy, N., & Danish, J. A. (2019). Roles, rules, and keys: How different play configurations shape collaborative science inquiry. *Journal of the Learning Sciences, 28*(4–5), 513–555. https://doi.org/10.1080/10508406.2019.1675071

Dennis, S. F. (2006). Prospects for qualitative GIS at the intersection of youth development and participatory urban planning. *Environment and Planning A: Economy and Space, 38*(11), 2039–2054. https://doi.org/10.1068/a3861

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Hall, R., Koschmann, T., Lemke, J. L., Sherin, M. G., & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *Journal of the Learning Sciences, 19*(1), 3–53. https://doi.org/10.1080/10508400903452884

Dickes, A. C., Kamarainen, A., Metcalf, S. J., Gün-Yildiz, S., Brennan, K., Grotzer, T., & Dede, C. (2019). Scaffolding ecosystems science practice by blending immersive environments and computational modeling. *British Journal of Educational Technology*, *0*(0), bjet.12806. https://doi.org/10.1111/bjet.12806

Eberbach, C., Hmelo-Silver, C. E., Jordan, R., Taylor, J., & Hunter, R. (2021). Multidimensional trajectories for understanding ecosystems. *Science Education, 105*(3), 521–540. https://doi.org/10.1002/sce.21613

Elwood, S. (2008). Volunteered geographic information: Key questions, concepts and methods to guide emerging research and practice. *GeoJournal, 72*(3–4), 133–135.

Elwood, S. (2011). Participatory approaches in GIS and society research: Foundations, practices, and future directions. *The SAGE handbook of GIS and society*, 381–399.

Elwood, S., & Mitchell, K. (2012). Mapping children's politics: Spatial stories, dialogic relations and political formation. *Geografiska Annaler, Series B: Human Geography, 94*(1), 1–15. https://doi.org/10.1111/j.1468-0467.2012.00392.x

Elwood, S., Goodchild, M. F., & Sui, D. Z. (2011). Researching volunteered geographic information: Spatial data, geographic research, and new social practice. *Annals of the Association of American Geographers, 102*(3), 571–590.

Enyedy, N. (2010). Inventing mapping: Creating cultural forms to solve collective problems. *Cognition and Instruction*https://doi.org/10.1207/s1532690xci2304_1

Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Constructing liminal blends in a collaborative augmented-reality learning environment. *International Journal of Computer-Supported Collaborative Learning, 10*(1), 7–34. https://doi.org/10.1007/s11412-015-9207-1

Enyedy, N., & Mukhopadhyay, S. (2007). They don't show nothing I didn't know: Emergent tensions between culturally relevant pedagogy and mathematics pedagogy. *The Journal of the Learning Sciences, 16*(2), 139–174.

Forsythe, M. (2018). Sampling in the wild: How attention to varaition supports middle school students' sampling practices. *Statistics Education Research Journal, 17*(1), 8–34.

Frausto Aceves, A., & Morales-Doyle, D. (2022). More than civil engineering and civic reasoning: World-building in middle school STEM. *Occasional Paper Series*, *48*, 13–32. https://doi.org/10.58295/2375-3668.1473

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education, 104*(6), 953–982. https://doi.org/10.1002/sce.21592

Haklay, M., Singleton, A., & Parker, C. (2008). Web mapping 2.0: The neogeography of the GeoWeb. *Geography Compass, 2*(6), 2011–2039.

Hall, R., Shapiro, B. R., Hostetler, A., Lubbock, H., Owens, D., Daw, C., & Fisher, D. (2020). Here-and-then: Learning by making places with digital spatial story lines. *Cognition and Instruction, 38*(3), 348–373. https://doi.org/10.1080/07370008.2020.1732391

Hall, R., Stevens, R., & Torralba, T. (2002). Disrupting representational infrastructure in conversations across disciplines. *Mind, Culture, and Activity, 9*(3), 179–210. https://doi.org/10.1207/S15327884MCA0903_03

Hart, R. (1979). *Children's experience of place*. Irvington.

Headrick Taylor, K. (2017). Learning along lines: Locative literacies for reading and writing the city. *Journal of the Learning Sciences, 26*(4), 533–574. https://doi.org/10.1080/10508406.2017.1307198

Hecht, M., & Nelson, T. (2021). Youth, place, and educator practices: Designing program elements to support relational processes and naturalist identity development. *Environmental Education Research*, *0*(0), 1–20. https://doi.org/10.1080/13504622.2021.1928608

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the Learning Sciences, 15*(1), 53–61. https://doi.org/10.1207/s15327809jls1501_7

Huffling, L. D., Carlone, H. B., & Benavides, A. (2017). Re-inhabiting place in contemporary rural communities: Moving toward a critical pedagogy of place. *Cultural Studies of Science Education, 12*(1), 33–43. https://doi.org/10.1007/s11422-016-9756-2

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39–103. https://doi.org/10.1207/s15327809jls0401_2

Kahn, J., & Jiang, S. (2020). Learning with large, complex data and visualizations: Youth data wrangling in modeling family migration. *Learning, Media and Technology*, *0*(0), 1–16. https://doi.org/10.1080/17439884.2020.1826962

Kamarainen, A. M., Metcalf, S., Grotzer, T., & Dede, C. (2015). Exploring ecosystems from the inside: How immersive multi-user virtual environments can support development of epistemologically grounded modeling practices in ecosystem science instruction. *Journal of Science Education and Technology, 24*(2–3), 148–167. https://doi.org/10.1007/s10956-014-9531-7

Kastens, K. A., & Liben, L. S. (2010). Children's strategies and difficulties while using a map to record locations in an outdoor environment. *International Research in Geographical and Environmental Education, 19*(4), 315–340. https://doi.org/10.1080/10382046.2010.519151

Katz, C. (2019). Children and childhood. In *Keywords in Radical Geography: Antipode at 50* (pp. 40–44). https://doi.org/10.5040/9781350035164.ch-003

Keifert, D., Lee, C., Enyedy, N., Dahn, M., Lindberg, L., & Danish, J. (2020). Tracing bodies through liminal blends in a mixed reality learning environment. *International Journal of Science Education*, *0*(0), 1–23. https://doi.org/10.1080/09500693.2020.1851423

Kelly, G. J., & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education, 86*(3), 314–342. https://doi.org/10.1002/sce.10024

Kissling, M. T., & Calabrese Barton, A. M. (2015). Place-based education: (Re)integrating ecology & economy. *Occasional Paper Series, 33*(15), 6.

Kuhn, D., & Dean Jr, D. (2005). Is developing scientific thinking all about learning to control variables?. *Psychological Science, 16*(11), 866–870.

Lanouette, K. (2022). Emotion, place and practice: Exploring the interplay in children's engagement in ecologists' sampling practices. *Science Education, 106*, 610–644. https://doi.org/10.1002/sce.21702

Lanouette, K. & Taylor, K. H. (Eds). (2022). Learning within socio-political landscapes: (Re)imagining children's geographies. *Occasional Paper Series*, (48), 3–12. https://doi.org/10.58295/2375-3668.1471

Lanouette, K. & Van Wart, S. (2019). Moving between experience, data and explanation: The role of interactive GIS maps in elementary science sensemaking. In K. Lund, G. Niccolai, E. Lavoué, C.H. Gweon & M. Baker (Eds.), "A wide lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings," *Proceedings of the International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (Vol. 2, pp. 553–556). Lyon, France: International Society of the Learning Sciences. https://repository.isls.org//handle/1/4453

Lanouette K., Van Wart, S., & Parikh, T. (2016). Supporting elementary students' science learning through data modeling and interactive mapping in local spaces. In C.K. Looi, J. Polman, U. Cress & P. Reimann (Eds.), "Transforming learning, empowering learners," *Proceedings of the International Conference of the Learning Sciences (ICLS) 2016* (Vol. 1, pp. 570–577). Singapore: International Society of the Learning Sciences. https://repository.isls.org/handle/1/164

Lanouette, K., Cortes, K. L., Lopez, L., Bakal, M., & Wilkerson, M. H. (2024). Exploring climate change through students' place connections and public data sets. *Science Scope, 47*(3), 18–25. https://doi.org/10.1080/08872376.2024.2340444

Leander, K. M., Phillips, N. C., & Taylor, K. H. (2010). The changing social spaces of learning: Mapping new mobilities. *Review of Research in Education, 34*(1), 329–394. https://doi.org/10.3102/0091732X09358129

Learning in Places Collaborative. (2020). *Framework: Complex socio-ecological systems*. Bothell, Seattle, WA & Evanston, Il: Learning in Places.

Lee, V. R., Wilkerson, M. H., & Lanouette, K. (2021). A call for a humanistic stance toward K-12 data science education. *Educational Researcher, 50*(9), 664–672. https://doi.org/10.3102/0013189X21104881

Lehrer, R., & Pritchard, C. (2002). Symbolizing space into being. In *Symbolizing, modeling and tool use in mathematics education* (pp. 59–86). https://doi.org/10.1007/978-94-017-3194-2_5

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education, 96*(4), 701–724. https://doi.org/10.1002/sce.20475

Lehrer, R., & Schauble, L. (2017). Children's conceptions of sampling in local ecosystems investigations. *Science Education, 101*(6), 968–984. https://doi.org/10.1002/sce.21297

Lehrer, R., Schauble, L., & Lucas, D. (2008). Supporting development of the epistemology of inquiry. *Cognitive Development, 23*(4), 512–529. https://doi.org/10.1016/J.COGDEV.2008.09.001

Lim, M., & Barton, A. C. (2006). Science learning and a sense of place in a urban middle school. In *Cultural Studies of Science Education* (Vol. 1, Issue 1). https://doi.org/10.1007/s11422-005-9002-9

Lim, M., & Barton, A. C. (2010). Exploring insideness in urban children's sense of place. *Journal of Environmental Psychology, 30*(3), 328–337. https://doi.org/10.1016/j.jenvp.2010.03.002

Loh, B., Radinsky, J., Reiser, B. J., Gomez, L. M., Edelson, D. C., & Russell, E. (1997). The progress portfolio: promoting reflective inquiry in complex investigation environments. *Computer Supported Collaborative Leraning*, 169–178.

Louca, L. T., & Zacharia, Z. C. (2015). Examining learning through modeling in K-6 science education. *Journal of Science Education and Technology, 24*(2–3), 192–215. https://doi.org/10.1007/s10956-014-9533-5

Manz, E. (2012). Understanding the codevelopment of modeling practice and ecological knowledge. *Science Education, 96*(6), 1071–1105.

Manz, E. (2015a). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research, 85*(4), 553–590. https://doi.org/10.3102/0034654314558490

Manz, E. (2015b). Resistance and the development of scientific practice: Designing the mangle into science instruction. *Cognition and Instruction, 33*(2), 89–124. https://doi.org/10.1080/07370008.2014.1000490

Manz, E. (2016). Examining evidence construction as the transformation of the material world into community knowledge. *Journal of Research in Science Teaching, 53*(7), 1113–1140. https://doi.org/10.1002/tea.21264

Marin, A. (2020). Ambulatory sequences: Ecologies of learning by attending and observing on the move. *Cognition and Instruction, 38*(3), 281–317. https://doi.org/10.1080/07370008.2020.1767104

Martin, D. G. (2003). "Place-Framing" as place-making: Constituting a neighborhood for organizing and activism. *Annals of the Association of American Geographers, 93*(3), 730–750. https://doi.org/10.1111/1467-8306.9303011

McGowan, V. C., & Bell, P. (2022). "I now deeply care about the effects humans are having on the world": Cultivating ecological care and responsibility through complex systems modelling and investigations. *Educational and Developmental Psychologist, 39*(1), 1–16. https://doi.org/10.1080/20590776.2022.2027212

Metz, K. E. (2011). Disentangling robust developmental constraints from the instructionally mutable: Young children's epistemic reasoning about a study of their own design. *Journal of the Learning Sciences, 20*(1), 50–110. https://doi.org/10.1080/10508406.2011.529325

Metz, K. E., Cardace, A., Berson, E., Ly, U., Wong, N., Sisk-Hilton, S., Metz, S. E., & Wilson, M. (2019). Primary grade children's capacity to understand microevolution: The power of leveraging their fruitful intuitions and engagement in scientific practices. *Journal of the Learning Sciences, 28*(4–5), 556–615. https://doi.org/10.1080/10508406.2019.1667806

Mitchell, L. S. (1991). *Young geographers: How they explore the world and how they map the world [4th ed.]*. Bank Street College of Education.

Mitchell, K., & Elwood, S. (2012). Engaging Students through Mapping Local History. *Journal of Geography, 111*(4), 148–157. https://doi.org/10.1080/00221341.2011.624189

Morales-Doyle, D., & Frausto, A. (2021). Youth participatory science: A grassroots science curriculum framework. *Educational Action Research, 29*(1), 60–78. https://doi.org/10.1080/09650792.2019.1706598

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13165

National Academies of Sciences, Engineering, and Medicine. (2024). *Equity in K-12 STEM Education: Framing Decisions for the Future*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26859

Nespor, J. (2010). *Tangled up in school: Politics, space, bodies, and signs in the educational process*. Routledge.

Nespor, J. (2008). Education and place: A review essay. *Educational Theory, 58*(4), 475–489. https://doi.org/10.1111/j.1741-5446.2008.00301.x

Pierson, A. E., Clark, D. B., & Sherard, M. K. (2017). Learning progressions in context: Tensions and insights from a semester-long middle school modeling curriculum. *Science Education, 101*(6), 1061–1088. https://doi.org/10.1002/sce.21314

Pugh, P., McGinty, M., & Bang, M. (2019). Relational epistemologies in land-based learning environments: Reasoning about ecological systems and spatial indexing in motion. *Cultural Studies of Science Education, 14*(2), 425–448. https://doi.org/10.1007/s11422-019-09922-1

Radinsky, J. (2008). Students' roles in group-work with visual data: A site of science learning. *Cognition and Instruction, 26*(2), 145–194. https://doi.org/10.1080/07370000801980779

Radinsky, J. (2020). Mobilities of data narratives. *Cognition and Instruction, 38*(3), 374–406. https://doi.org/10.1080/07370008.2020.1717492

Radinsky, J., Hospelhorn, E., Melendez, J. W., Riel, J., & Washington, S. (2014). Teaching American migrations with GIS census webmaps: A modified "backwards design" approach in middle-school and college classrooms. *Journal of Social Studies Research, 38*(3), 143–158. https://doi.org/10.1016/j.jssr.2014.02.002

Radinsky, J., Oliva, S., & Alamar, K. (2010). Camila, the earth, and the sun: Constructing an idea as shared intellectual property. *Journal of Research in Science Teaching, 47*(6), 619–642. https://doi.org/10.1002/tea.20354

Radke, S. C., Vogel, S. E., Ma, J. Y., Hoadley, C., & Ascenzi-Moreno, L. (2022). Emergent bilingual middle schoolers' syncretic reasoning in statistical modeling. *Teachers College Record, 124*(5), 206–228. https://doi.org/10.1177/01614681221104141

Reigh, E., Escudé, M., Bakal, M., Rivero, E., Wei, X., Roberto, C., Hernández, D., Yada, A., Gutiérrez, K., & Wilkerson, M. H. (2022). Mapping racespace: Data stories as a tool for environmental and spatial justice. *Occasional Paper Series*, *2022*(48), 79–95. https://doi.org/10.58295/2375-3668.1452

Roberts, J., & Lyons, L. (2020). Examining spontaneous perspective taking and fluid self-to-data relationships in informal open-ended data exploration. *Journal of the Learning Sciences, 29*(1), 32–56. https://doi.org/10.1080/10508406.2019.1651317

Rosenberg, J. M., Schultheis, E. H., Kjelvik, M. K., Reedy, A., & Sultana, O. (2022). Big data, big changes? The technologies and sources of data used in science classrooms. *British Journal of Educational Technology, 53*(5), 1179–1201. https://doi.org/10.1111/bjet.13245

Rubel, L. H., Hall-Wieckert, M., & Lim, V. Y. (2017). Making space for place: Mapping tools and practices to teach for spatial justice. *Journal of the Learning Sciences, 26*(4), 643–687. https://doi.org/10.1080/10508406.2017.1336440

Ryokai, K., & Agogino, A. (2013). Off the paved paths: Exploring nature with a mobile augmented reality learning tool. [References]. *International Journal of Mobile Human Computer Interaction, 2*, 21–49. https://doi.org/10.4018/jmhci.2013040102

Sakr, M., Jewitt, C., Price, S., Sakr, M., Jewitt, C., & Price, S. (2016). Mobile experiences of historical place: A multimodal analysis of emotional engagement. *Journal of the Learning Sciences, 25*(1), 51–92. https://doi.org/10.1080/10508406.2015.1115761

Saldaña, J. (2021). *The Coding Manual for Qualitative Researchers*. 4th ed. Sage.

Sandoval, W. A., & Çam, A. (2011). Elementary children's judgments of the epistemic status of sources of justification. *Science Education, 95*(3), 383–408. https://doi.org/10.1002/sce.20426

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the learning sciences, 23*(1), 18–36.

Sandoval, W. A., Enyedy, N., Redman, E. H., & Xiao, S. (2019). Organising a culture of argumentation in elementary science. *International Journal of Science Education, 41*(13), 1848–1869. https://doi.org/10.1080/09500693.2019.1641856

Saxe, G. B. (2012). *Cultural development of mathematical ideas: Papua New Guinea studies*. Cambridge University Press.

Saxe, G. B., & Esmonde, I. (2005). Studying cognition in flux: A historical treatment of fu in the shifting structure of Oksapmin mathematics. *Mind, Culture, and Activity, 12*(3–4), 171–225. https://doi.org/10.1080/10749039.2005.9677810

Schwarz, C. V, Li, K., Salgado, M., & Manz, E. (2022). Beyond assessing knowledge about models and modeling: Moving toward expansive, meaningful, and equitable modeling practice. *Journal of Research in Science Teaching*, *March*, 1–11. https://doi.org/10.1002/tea.21770

Seyer-Ochi, l . (2006). Lived andscapes of the Filmore. In: L. Spind er, & G. Hammond (Eds.), *Innovations in Educational Ethnography* (pp. 169—232). Lawrence Erlbaum Associates.

Sieber, R. (2006). Public participation geographic information systems: A literature review and framework. *Annals of the Association of American Geographers, 96*(3), 491–507.

Singer, M., Radinsky, J., & Goldman, S. R. (2008). The role of gesture in meaning construction. *Discourse Processes, 45*(4–5), 365–386. https://doi.org/10.1080/01638530802145601

Sobel, D. (1998). *Mapmaking with children: Sense of place education for the elementary years*. Heinemann

Stroupe, D., & Carlone, H. B. (2021). Leaving the laboratory: Using field science to disrupt and expand historically enduring narratives of science teaching and learning. *Science & Education*, *0123456789*. https://doi.org/10.1007/s11191-021-00296-x

Switzer, A., Schwille, K., Russell, E., & Edelson, D. (2012). National Geographic FieldScope: A platform for community geography. *Frontiers in Ecology and the Environment, 10*(6), 334–335. https://doi.org/10.1890/110276

Takeuchi, M. A. (2021). Geopolitical configuration of identities and learning: Othering through the institutionalized categorization of "English language learners. *Cognition and Instruction, 39*(1), 85–112. https://doi.org/10.1080/07370008.2020.1825438

Taylor, K. H., & Hall, R. (2013). Counter-mapping the neighborhood on bicycles: Mobilizing youth to reimagine the city. *Technology, Knowledge and Learning, 18*(1–2), 65–93.

Taylor, K. H. (2017). Learning along lines: Locative literacies for reading and writing the city. *Journal of the Learning Sciences, 26*(4), 533–574.

Tulloch, D. L. (2008). Is VGI participation? From vernal pools to video games. *GeoJournal, 72*, 161–171.

Van Wart, S.J., Tsai, K. J., & Parikh, T.S. (2010). Local ground: A paper-based toolkit for documenting local geo-spatial knowledge. Proceedings of the First ACM Symposium on Computing for Development (ACMDEV) (123–128). Egham, UK.

Van Wart, S.J. & Parikh, T.S. (2013). Increasing youth and community agency in GIS. Paper Presented at the Geographic Human-Computer Interaction (GeoHCI) Workshop at SIGCHI (1–3). Paris, FR.

Van Wart, S., Lanouette, K., & Parikh, T. (2020). Scripts and counter-scripts in community-based data science: Participatory digital mapping and the pursuit of a Third Space. *Journal of the Learning Sciences, 29*(1), 127–153. https://doi.org/10.1080/10508406.2019.1693378

Wilkerson-Jerde, M. H., Gravel, B. E., & Macrander, C. A. (2015). Exploring shifts in middle school learners' modeling activity while generating drawings, animations, and computational simulations of molecular diffusion. *Journal of Science Education and Technology, 24*(2–3), 396–415. https://doi.org/10.1007/s10956-014-9497-5

Wilson, K., Coen, S. E., Piaskoski, A., & Gilliland, J. A. (2019). Children's perspectives on neighbourhood barriers and enablers to active school travel: A participatory mapping study. *Canadian Geographer, 63*(1), 112–128. https://doi.org/10.1111/cag.12488

Zimmerman, H. T., & Land, S. M. (2014). Facilitating place-based learning in outdoor informal environments with mobile computers. *TechTrends, 58*(1), 77–83. https://doi.org/10.1007/s11528-013-0724-3

Zimmerman, H. T., Land, S. M., McClain, L. R., Mohney, M. R., Choi, G. W., & Salman, F. H. (2015). Tree Investigators: Supporting families' scientific talk in an arboretum with mobile computers. *International Journal of Science Education, Part b: Communication and Public Engagement, 5*(1), 44–67. https://doi.org/10.1080/21548455.2013.832437