JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

Intern. J. Comput.-Support. Collab. Learn
https://doi.org/10.1007/s11412-017-9264-8

Developing & using interaction geography in a museum

Ben Rydal Shapiro[1] · **Rogers P. Hall**[1] · **David A. Owens**[1]

Received: 9 September 2017 / Accepted: 2 November 2017

Abstract There are many approaches that support studies of learning in relation to the physical environment, people's interaction with one another, or people's movement. However, what these approaches achieve in granularity of description, they tend to lose in synthesis and integration, and to date, there are not effective methods and concepts to study learning in relation to all of these dimensions simultaneously. This paper outlines our development and use of a new approach to describing, representing, and interpreting people's interaction as they move within and across physical environments. We call this approach interaction geography. It provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings. The first part of this paper illustrates our development and use of interaction geography to study visitor engagement in a cultural heritage museum. In particular, we illustrate *Mondrian Transcription,* a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS),* a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. The second part of the paper describes one team of museum educators, curators, archivists, and exhibit designers using a computer-supported collaborative learning (CSCL) environment based on interaction geography. We show how this environment used interaction geography to disrupt the conventional views of visitor engagement and learning that museum professionals hold and then reframe these disruptions to enable museum professionals to perceive visitor engagement and learning in innovative ways that potentially support their future design decisions. We conclude the paper by discussing how this work may serve as a blueprint to guide future efforts to expand interaction geography in ways that explore new collaborations across the fields of education, information visualization, architecture, and the arts.

Keywords Interaction geography · Interaction analysis · Time geography · Computer-supported collaborative learning · Learning sciences · Museum studies · Information visualization · Architecture

✉ Ben Rydal Shapiro
ben@benrydal.com

[1] Vanderbilt University Peabody College of Education and Human Development, Nashville, TN, USA

Introduction

There are many approaches that support studies of learning in relation to the physical environment, people's interaction with one another, or people's movement. For example, post-occupancy evaluation (Zimring & Reizenstein, 1980; Cleveland & Fisher, 2013) encompasses approaches that support studies of how the physical layout of classrooms, museums, and workplaces influences people's learning by conditioning their behavior (Monahan, 2002; Cleveland, 2009; Scott-Webber, 2004; Wineman et al., 2006; Peponis et al., 1990). Conversation analysis (Erickson, 2004; Ludvigsen et al., 2016; Stahl et al., 2006) and interaction analysis (Jordan & Henderson, 1995; Hall and Stevens, 2015) support studies that unpack how technology-mediated interactions between people make up social learning contexts (Cress, 2008; Stahl et al., 2014; Suthers et al., 2010; Davidsen & Ryberg, 2017; Leander, 2002). Movement based approaches (Hagerstrand, 1970, Cresswell, 2010; Sheller & Urry, 2006; Kwan and Lee, 2003) support studies that investigate how people realize or miss learning opportunities as they move across contexts over the course of days, months, and even years (Taylor & Hall, 2013; Marin, 2013; Ito et al., 2009).

However, what these approaches achieve in granularity of description, they tend to lose in synthesis and integration. For example, post-occupancy evaluation typically ignores people's conversation and the sequential organization of people's movement (Shapiro, 2017a). Interaction and conversation analysis traditionally disregard the physical environment and people's movement beyond the scale of artifacts and gesture (Flood et al., 2015; Marin, 2013; Lemke, 2000). Movement based approaches do not operate at a scale relevant to people's interaction with one another or the physical environment of settings like classrooms or museum gallery spaces (Scollon, 2008; Hall and Stevens, 2015).

The lack of integrative approaches that simultaneously consider the physical environment, people's interaction with one another, and people's movement hinders learning research and professional design practice particularly in informal learning settings. For example, the assessment of visitor engagement and learning in museums is often simplified to important but basic questions such as how long people remain at exhibits. This is because museum researchers and designers are not able to take account of other factors such as how visitors recruit the attention of family members or peers to engage with the designed content of museum galleries; how they relate one exhibit to another (e.g., making return trips to seek additional information); and how they collect, edit, and share their experiences with one another through their movement across a complete museum visit. Put differently, informal learning settings like museums are places in need of assumptions and methods that are not school-based (Schauble et al., 1997) and ideally require ways to link fine grained analyses of visitor conversation, interaction, and embodied activities at single museum exhibits (Crowley & Jacobs, 2002; Steier, 2014; Stevens & Hall, 1997) with broader analyses of how visitors make sense of intended museum design across gallery spaces and complete museum visits (Tzortzi, 2014).

This paper outlines our development and use of a new approach to describing, representing, and interpreting people's interaction as they move within and across physical environments. We call this approach interaction geography. It provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings. The first part of this paper illustrates our development and use of interaction geography to study visitor engagement in a cultural heritage museum. In particular, we

illustrate *Mondrian Transcription,* a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS),* a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. The second part of the paper describes how a team of museum educators, curators, archivists, and exhibit designers used a computer-supported collaborative learning (CSCL) environment based on interaction geography. We show how this environment used interaction geography to disrupt the conventional views of visitor engagement and learning that museum professionals hold and then reframe these disruptions to enable museum professionals to perceive visitor engagement and learning in innovative ways that potentially support their future design decisions. We conclude the paper by discussing how this work may guide future efforts to expand interaction geography in ways that explore new collaborations across the fields of education, information visualization, architecture, and the arts.

Museum setting & empirical basis

The setting and empirical basis of this research is a three year project to understand how visitors cultivate interests in and learn about the diverse historical and cultural heritage of American Roots and Country music as they visit a nationally renowned museum located in the mid-South region of the United States.

Three primary research questions guided our work within this museum context. First, we wanted to describe the interaction and conversation patterns of visitors at single museum exhibits in relation to their movement across gallery spaces during their complete museum visit. Second, we wanted to use these descriptions to better understand how visitors furthered their own personal interests, cultural identities, and interest-driven learning. Third, we wanted to see if and how exploration of visitor activity using new types of computer-supported collaborative learning environments could advance the professional insights and vision (Goodwin, 1994) among museum professionals to identify ways to design more equitable, expansive, and productive learning opportunities in museum gallery spaces.

These questions required new types of research data as well as new ways to represent and interpret this research data. In particular, the first two questions required detailed, multi-perspective accounts of the conversation, technology-mediated interaction, and movement of groups of visitors across complete museum visits along with new ways to describe, represent, and interpret these accounts that integrated the fields of education, information visualization, architecture, and the arts. The third question required linking the rich body of literature within the CSCL community concerning the use of tools, especially video-based tools, in forms of reflective professional practice (see Erickson, 2007; Zahn et al., 2012; Ligorio & Ritella, 2010; Johansson et al., 2017; Lymer et al., 2009; Cress et al., 2015) with techniques from information visualization and computational information design (Stasko et al., 2008; Fry, 2004) in ways that advanced the work of professional practitioners at this museum.

To answer the first two questions, we collaborated with museum partners and participating visitor groups/families over a period of six weeks to collect a purposive sample of complete museum visits across 22 visitor group cases (2–5 visitors per group), including 11 family groups. Data from these 22 case studies included continuous, multi-perspective video and audio records (72 h total) of visitor group movement, interaction, and social media/technology use. These data were collected through small, unobtrusive cameras worn by visitors (as necklaces) for the duration of their visit with no researchers present (visits ranged from 30 min to 4 h). These data subsequently required developing new ways

to organize, represent and make sense of large quantities of multi-perspective audio and video records over space and time (e.g., up to 5 simultaneous streams of audio/video per visitor group) along with detailed transcripts of visitors' conversation and movement. Data also included 1–2 h post-visit interviews with all visitor groups, which often included walks back through the museum with researchers. Data also included traces of online content (e.g., photographs, videos, online conversations) that visitors gathered (e.g., with cell phones/cameras) and shared with others on various social media platforms during and after their visit.

To answer the third question, we collected audio, video and survey data from a series of professional development and design workshops with museum educators, curators, archivists, and exhibit designers. These workshops are part of a larger design study (Cobb et al., 2003) that aims to advance museum professionals' learning about how design practice can create opportunities for interest-driven learning in and beyond their gallery spaces.

Visualizing & studying visitor engagement

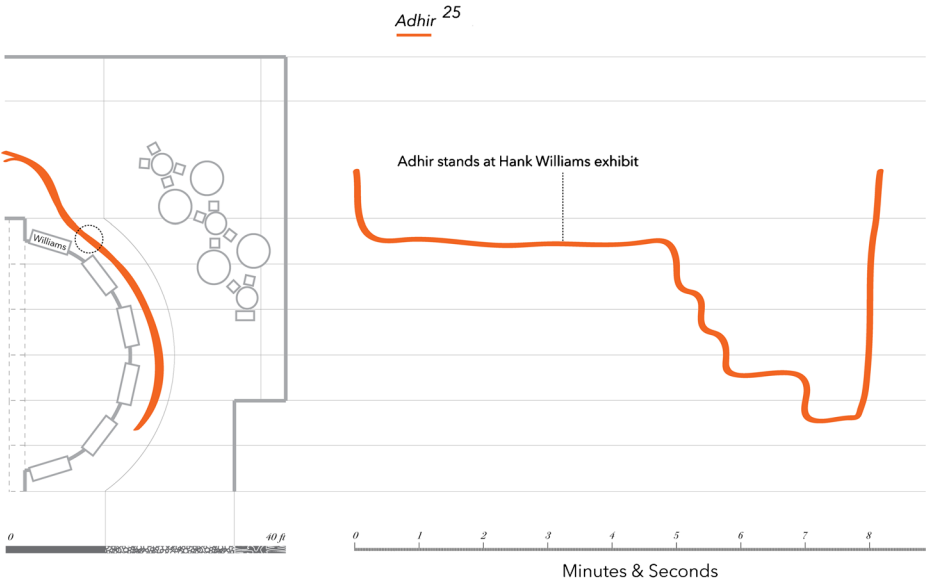
We now describe our development and use of interaction geography to visually transcribe museum visitors' interaction over space and through time and to study visitor engagement. Figure 1 adapts methods of time geography (Hagerstrand, 1970) to map the movement across a museum gallery space of a visitor we call Adhir. Adhir is 25 years old and is one member of a family of five, who we call the "Bluegrass Family". The left of the figure or "floor plan view" shows Adhir's movement as an orange path over a floor plan of the gallery space (i.e., looking down on the space). The right or "space-time view" (Hagerstrand, 1970) extends Adhir's movement on the floor plan horizontally over time. Also included is a rendering showing the gallery space from a point marked on the floor plan.

The floor plan view shows where Adhir goes within the gallery space, while the space-time view shows how he moves within the gallery space over time. For example, after entering the gallery space (top left of floor plan view and beginning of space-time view), Adhir walks towards an exhibit about Hank Williams (marked on the floor plan). Hank Williams is generally regarded as one of the most significant American singers and songwriters in the twentieth Century (Escott et al., 2004). Adhir stands for almost 5 min at the Hank Williams exhibit, and in the audio and video record, he seems to be moved to tears by what he finds there. His standing or deep engagement with the exhibit is indicated by a horizontal orange path in the space-time view that extends from approximately minutes 0–5 and corresponds to the vertical position of the Hank Williams exhibit.

Subsequently, Adhir moves and stands (as indicated by the other horizontal orange lines in the space-time view) for varying lengths of time at four of the five other exhibits that comprise a semicircular set of exhibits. From top to bottom on the floor plan, this semicircle includes exhibits on renowned Bluegrass and early Country musicians Hank Williams, Lester Flatt, Earl Scruggs, Bill Monroe, Maybelle Carter, and Jimmie Rodgers. Adhir concludes his visit to the gallery space by walking quickly back across these exhibits leaving the space where he entered and notably not visiting the Jimmie Rodgers exhibit.

Figure 2 maps in blue the movement of six-year-old Blake, another member of the Bluegrass Family, during his visit with Adhir to this gallery space. Blake's sister is Adhir's fiancé. All conventions and scaling match the previous figure. Line pattern distinguishes between three horizontal areas of space on the floor plan providing some description of horizontal movement on the floor plan in the space-time view.

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017



Q4 **Fig. 1** Adhir's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

Figure 2 illustrates not only where Blake and Adhir go within the gallery space and how they interact with exhibits but also how they interact with one another over space and time. For example, the space-time view shows that while Adhir stands at the Hank Williams exhibit, Blake moves quickly (apparently running as indicated by the sharp slope of his movement path) back and forth across the semicircle of exhibits in the gallery space. Closer analysis of Blake's efforts in the audio and video record confirm that his movement path reflects multiple, frantic attempts to draw Adhir away from the Hank Williams exhibit. After four failed attempts, Blake finally succeeds in leading Adhir on what we describe as a "tour" of other exhibits in the gallery, which occurs in Fig. 2 when their movement paths intertwine in space-time from approximately minutes 5–6.

Figure 3 displays the movement of two other members of the Bluegrass Family, Blake's brother Jeans (green) and their sister Lily (yellow), during the family's visit together to this

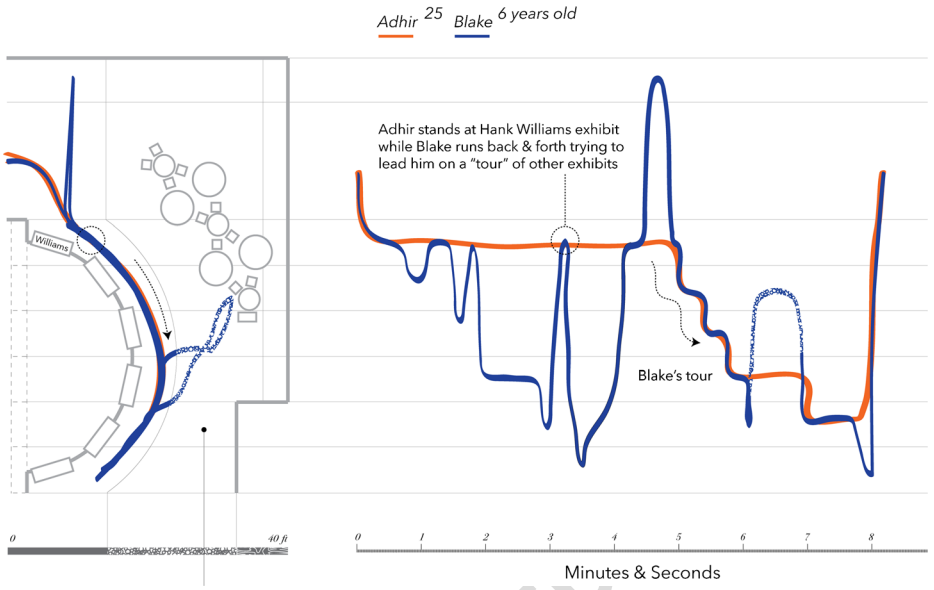


Fig. 2 Blake and Adhir's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

gallery space. The space-time view illustrates how Jeans and Lily nearly always move through the gallery space together (they were apart only during minutes 4–5).

Together, Figs. 2 and 3 illustrate how pairs within the Bluegrass Family move to engage with exhibits and one another in starkly different ways. While Blake displays a recruitment movement pattern in response to Adhir's extended pattern of reverence, Jeans and Lily

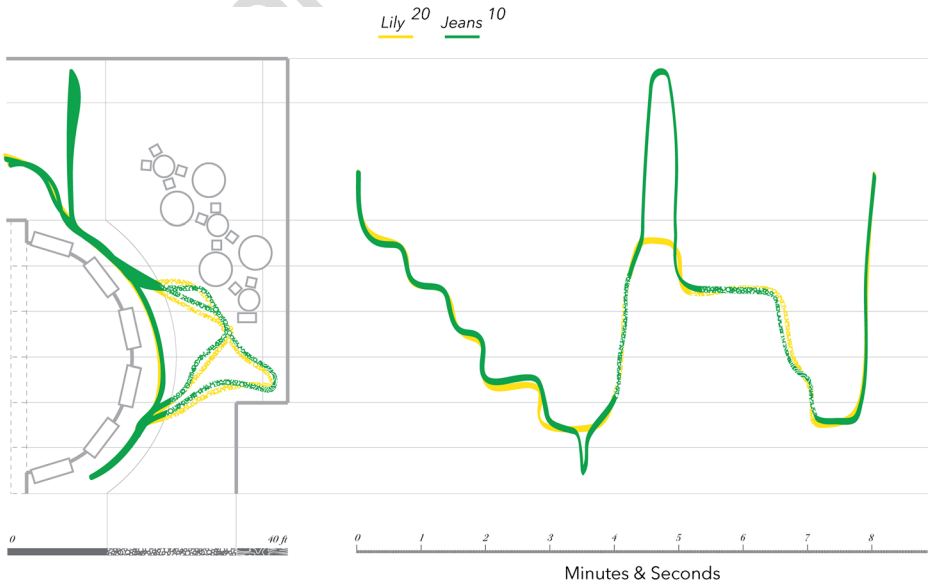


Fig. 3 Jeans and Lily's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

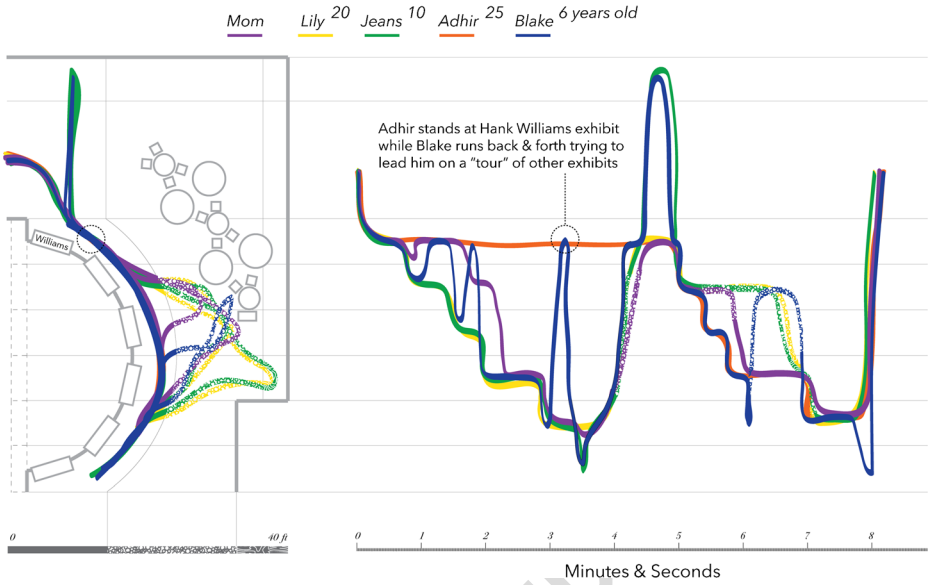


Fig. 4 The Bluegrass Family's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

produce intertwined movement, similar to the tour movement pattern later produced by Blake with Adhir.

Figure 4 maps the movement of all 5 members of the Bluegrass family and now includes Blake, Jeans and Lily's mom, Mae, in purple (e.g., we use the name "Mom" in the figure to emphasize Mae's role as a parent). The figure shows how the Bluegrass Family is intimately engaged with the semicircle of exhibits dedicated to famous Bluegrass and early Country musicians. On one hand, the figure reveals the family's dense and focused movement patterns in space and time at and across these exhibits (and not at other exhibits in the gallery). On the other hand, the figure shows visible qualities (e.g., pace, duration, shape, distance) and relationships (e.g., intersections, weaving, splitting, proximity) among movement paths that support and deepen different analytical framings of engagement. In particular, these qualities and relationships provide a means to study how the family engages by producing what some call a meshwork of movement (Ingold, 2007), within which they manage personal and social distances (Hall, 1966) between one another in relation to the spatial layout of the space.

For example, Fig. 4 illustrates how Adhir's movement and physical location anchors and influences the movement trajectories of other family members, particularly Blake. Furthermore, the figure suggests that Adhir and Lily are recipients of the younger boys' efforts to show what they have learned in the gallery during the family's visit to this space. As described in their post-visit interview, Blake, Jeans, and Mae had also visited the museum 2 days earlier. Close analysis of Fig. 4 suggests that Jeans, through his close and constant proximity to Lily, and Blake, through his constant efforts to lead Adhir on a tour, are sharing this gallery space with Adhir and Lily through their movement. Finally, the space-time view in Fig. 4 shows how Mae's movement often lags behind her family's movement and how she often re-joins her family at particular moments when they are stopped and gathered together at an exhibit. As we will show in detail later, these patterns helped us understand how Mae manages her children's engagement and learning by joining them at moments of peak

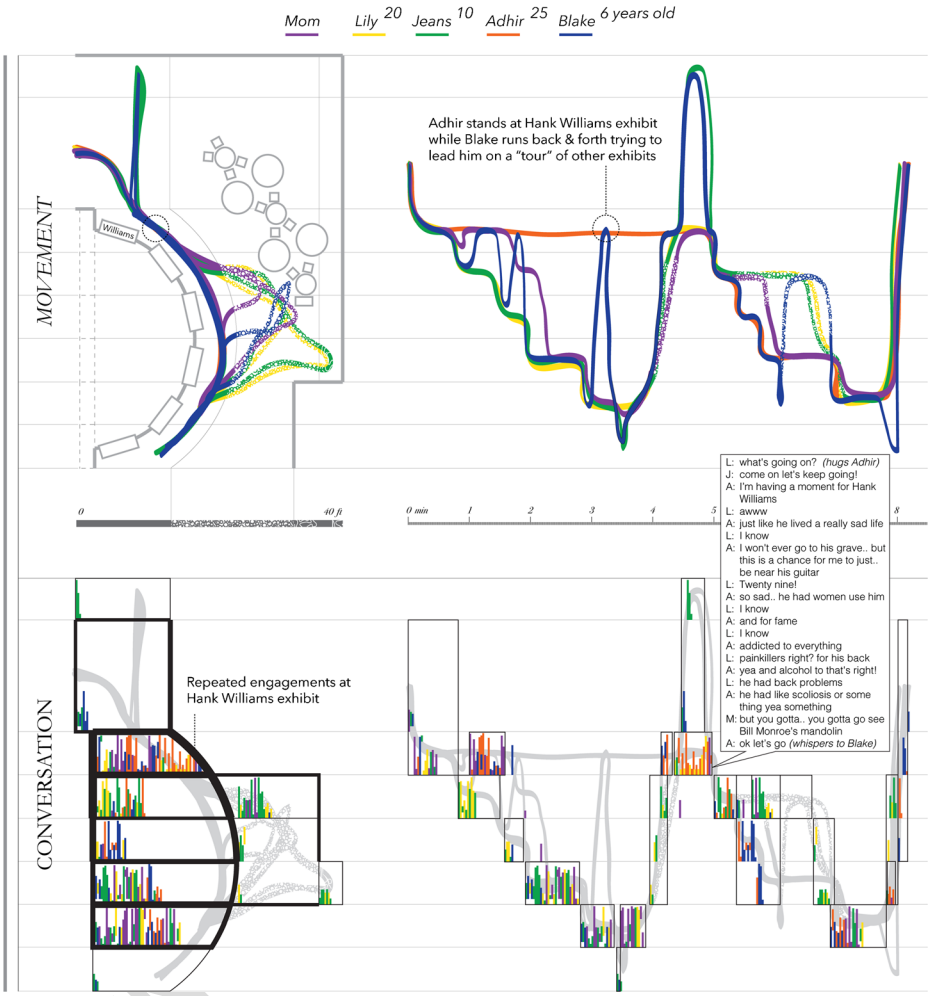


Fig. 5 Mondrian Transcript of the Bluegrass Family's interaction geography. Copyright © by Ben Rydal Shapiro. Reprinted by permission

engagement to make connections across exhibits for her children. The space-time view is essential to describing, representing, and interpreting visible qualities and relationships among movement paths that support different analytical framings of engagement.

Figure 5 extends the previous figures to illustrate more fully a way of transcribing people's interaction. We call this *Mondrian Transcription*, because it bears resemblance to the work of the Modernist artist, Piet Mondrian (1872–1944), particularly to his use of lines in relation to forms (e.g., visitor paths and graded regions of engagement through talk-in-interaction, in our usage). The top half of the figure once again shows the movement of all five members of the Bluegrass Family. The bottom half maps the Bluegrass Family's conversation in relation to their movement (i.e., the family's movement is shown in gray beneath their conversation to link the two halves of the figure).

In Fig. 5, conversation is transcribed and organized in a manner that draws from and extends conventions of conversation analysis used in the learning sciences and CSCL

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

communities (Derry et al., 2010; Jordan & Henderson, 1995; Stahl et al., 2006; also see Erickson, 2004, for analysis using conventions drawn from musical scoring). Given a typical line-ordered transcript, Mondrian Transcription shows each turn at talk as a colored line to indicate which family member contributes (i.e., speaks) that conversation turn (indentations indicate overlapping speech). Second, colored lines of talk are gathered into boxes that group topically related sequences of conversation turns and movement (e.g., usually related to artifacts/musicians). These sequences resemble what Ananda Marin (2013) calls ambulatory sequences or interleaved sequences of movement and talk among multiple people situated in and across the physical environment.

In other words, in the space-time view, each box marks the start, duration, and end of an ambulatory sequence and reveals how moments of conversational engagement are organized sequentially across the gallery space (Marin's work extends Adam Kendon's concept of a facing formation, see Kendon, 1990). For instance, the bottom half of Fig. 5 highlights one box in space-time, where the readable text expands the box of colored lines that, along with people's movement, represent an ambulatory sequence. In the floor plan view, ambulatory sequences accumulate over time within regions of gridded space to create what we call engagement footprints (similar to heat maps). For example, the region of space around the Hank Williams exhibit has the largest number of conversation turns (as indicated by the many colored lines of talk) and is enclosed by a dense box that reflects five separate (in time) ambulatory sequences occurring at the Hank Williams exhibit (the box thickness in the floor plan view increasing with each repeated ambulatory sequence). Such a dense engagement footprint indicates that the Bluegrass Family is intensely and repeatedly engaging with the Hank Williams exhibit. It also shows when and which family members facilitate this engagement through their conversation turns. The boxes in the figure reflect our decisions about what constitutes a thematic topic among interacting speakers; however, other researchers, designers or practitioners could use Mondrian Transcription to group and study conversation turns and movement in ways that suit their needs. Likewise, Mondrian Transcription could potentially incorporate additional types of conventions to, for example, indicate body positions, gestural drawings or the direction of talk (e.g., who is talking to whom).

Figure 5 conveys how interaction geography provides fundamentally new ways of describing, representing, and interpreting people's interaction in relation to their movement through the physical environment. For example, the ambulatory sequence (highlighted by the readable text) occurring from approximately minutes 4–5 in the space-time view encompasses a complex mesh of activity around the Hank Williams exhibit. This activity builds on the family's previous interaction in the gallery space and extends to other parts of the space. During this meshing of movement paths and talk, the family's movement and conversation in the space-time view become entangled in ways that reveal a complex sequence of interaction between family members in relation to their movement and the environment, during which:

1) Lily soothes the emotions of Adhir (her fiancé) by hugging and consoling him as he compares the Hank Williams exhibit to a "grave" (in line 8).
2) Jeans gives Lily and Adhir privacy by leading a frustrated Blake away from the Hank Williams exhibit (the extension of their movement paths upwards in the floor plan and space-time views indicating their movement away from the exhibit).
3) Blake and Jeans rejoin Lily and Adhir as Adhir continues to share his own account of Hank William's painful life.

4) Mae (Mom), who has been standing near Adhir and Lily and observing her family's interaction, helps Blake lead Adhir on a tour of other exhibits by saying to Adhir, "but you gotta.. you gotta go see Bill Monroe's mandolin" (in lines 22–23)
5) Evidently fully aware of Blake's ongoing project to lead a tour, Adhir whispers to Blake, "ok let's go" and they move forward together to the next Bluegrass artist (at the end of the highlighted conversation).

Our analysis is not possible without Mondrian Transcription, which provides a means to describe, represent, and interpret people's interaction in relation to their movement through physical environments. Second, our analysis reveals goals and intentions, which would not be visible without the integrative perspective that interaction geography affords. For the Bluegrass Family, these goals and intentions reveal how the family produces a personally edited (Lave et al., 1984; Ma & Munter, 2014) version of the gallery space, in which the exhibits they visit are a subset of what has been designed, and their engagements extend and elaborate the meaning of exhibits in ways relevant to their personal and social history. Third, our analysis characterizes an important ambulatory sequence within the Bluegrass Family's many ambulatory sequences in this gallery space. This sequence reflects a history of engagement that encompasses the sequence that finally releases Adhir from the Hank Williams exhibit to join Blake's tour. We call such important ambulatory sequences "engagement contours." The concept of an engagement contour draws from topographic mapping to provide a way to delineate how, where, and when people's interaction builds to produce moments of peak engagement over space and through time. In settings like museums, we suggest these moments may be quite important to how people pursue or realize their own interest-driven learning. Finally, and perhaps most relevant to the learning sciences and CSCL communities, our analysis shows how configurations of bodies and attention are as meaningful as utterances of spoken language, for making sense both of what has come before and what might come next. Just as a turn at talk can assess what has come before or project to a next topic, a shift in body proxemics can gather paths that have come before and project a next path in joint activity.

Figure 6 extends the previous analysis and discussion by showing how a different family can produce a very different interaction geography in this same gallery space. "The Women in Music Family" includes a mother (Hsu), her two college age daughters (Rachel and Maya) and their female cousin (Amy). All scales match the previous figure.

The Women in Music Family's movement over the floor plan indicates how the family engages with entirely different exhibits than those visited by the Bluegrass Family. As the space-time view shows, the family spends the majority their time at a set of exhibits that line the entire right wall of the floor plan. These exhibits are dedicated to Crystal Gayle, the first female country artist to achieve a platinum selling album (*We Must Believe in Magic*, 1977). Likewise, the family's movement over space-time shows how the family members remain tightly intertwined throughout their visit to this gallery space. Moreover, the family's engagement footprints (boxes and conversation turns in the floor plan view) are less dense in comparison to those of the Bluegrass Family. The highlighted conversation in the figure shows how the family personalizes exhibit content. During this conversation, Hsu tells a story about how Amy's mother and father met Crystal Gayle. The daughters comment that Amy's mother resembles Crystal Gayle and they discuss a photograph of her mother taken with Kenny Chesney.

These observations illustrate how families can engage with the same gallery space in very different ways. Once again, this analysis and related interpretations are not possible without the descriptive and representational power of Mondrian Transcription, which provides a way to

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

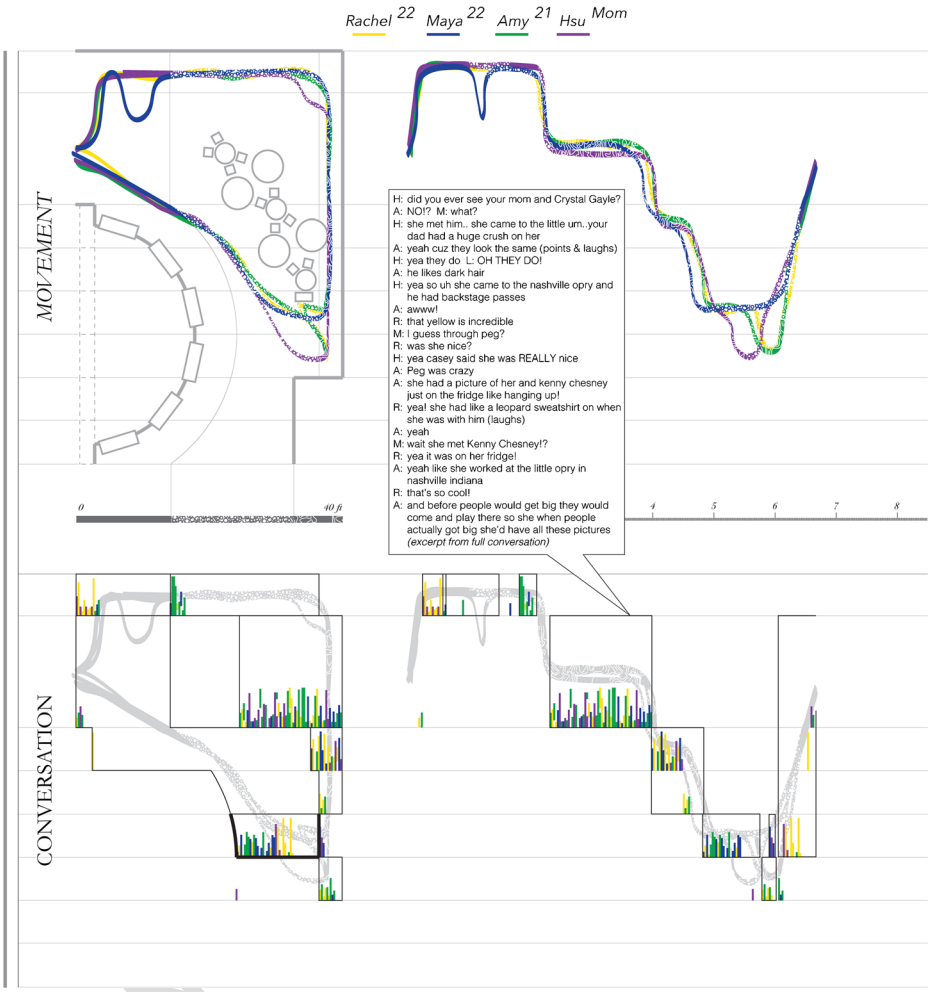


Fig. 6 Mondrian Transcript of the Women in Music Family's interaction geography. Copyright © by Ben Rydal Shapiro. Reprinted by permission

unpack people's movement and conversation at varying levels of detail as they move across the environment to draw comparisons, make associations, and conduct analyses at both individual and group levels.

Figures 7 and 8 are screenshots from a dynamic visualization tool we call the *Interaction Geography Slicer (IGS)*. As we will describe more completely later in this paper, the IGS allows for new forms of interaction and multimodal analysis by using Mondrian Transcription in a variety of ways. The figures compare the movement and conversation of four different families in three different museum gallery spaces. The first screenshot shows movement and the second shows conversation using the conventions described previously. Columns distinguish different families, while rows distinguish different gallery spaces. These spaces roughly correspond to galleries visitors experience at the beginning (Folk Roots Gallery), middle (Bluegrass Gallery) and end (Rotunda Gallery) of their complete museum visit. All displayed information is set to the same scales. Since the Taylor Swift Family did not visit the Rotunda Gallery, we have assembled

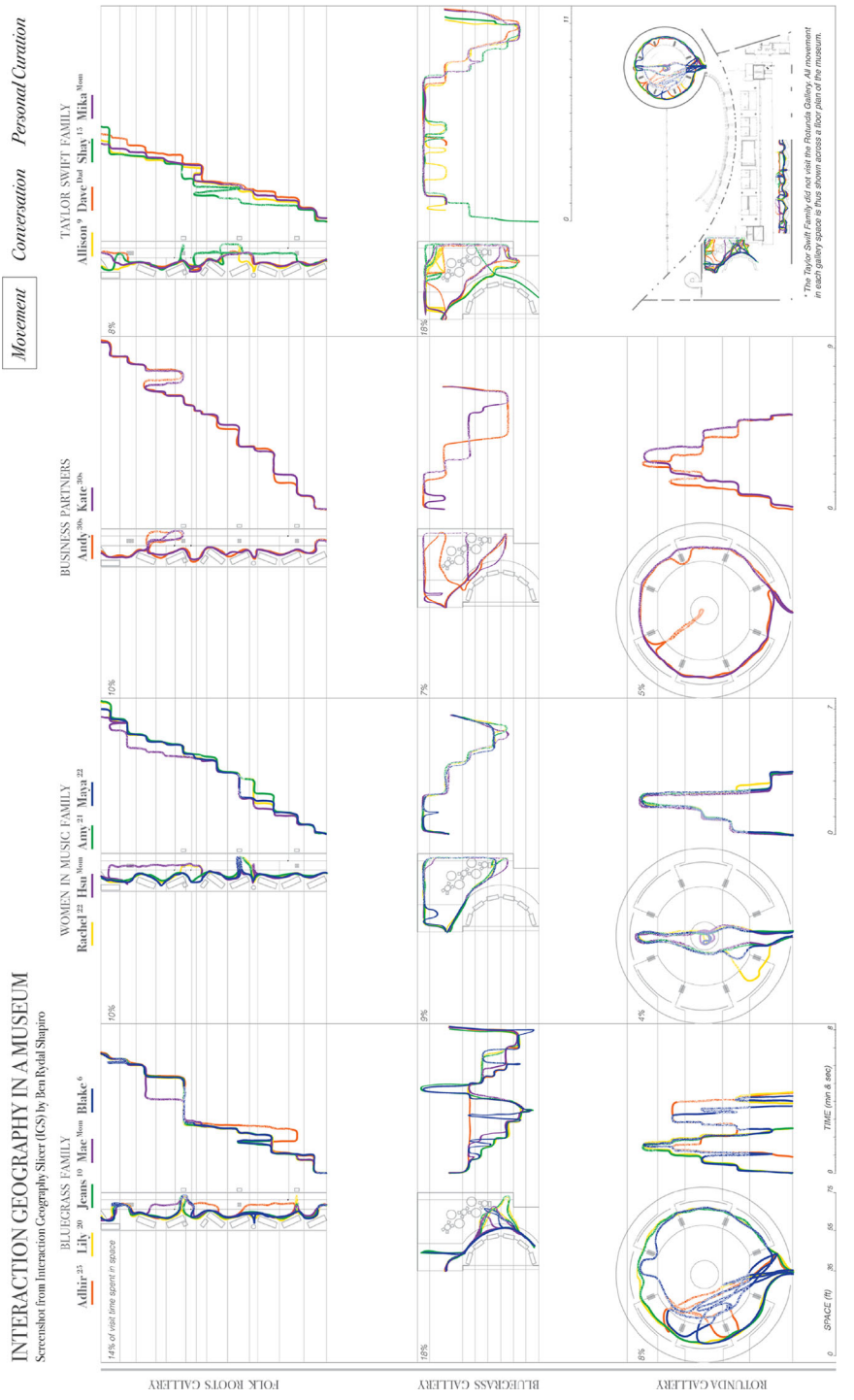


Fig. 7 Screenshot from Interaction Geography Slicer (IGS) showing movement of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

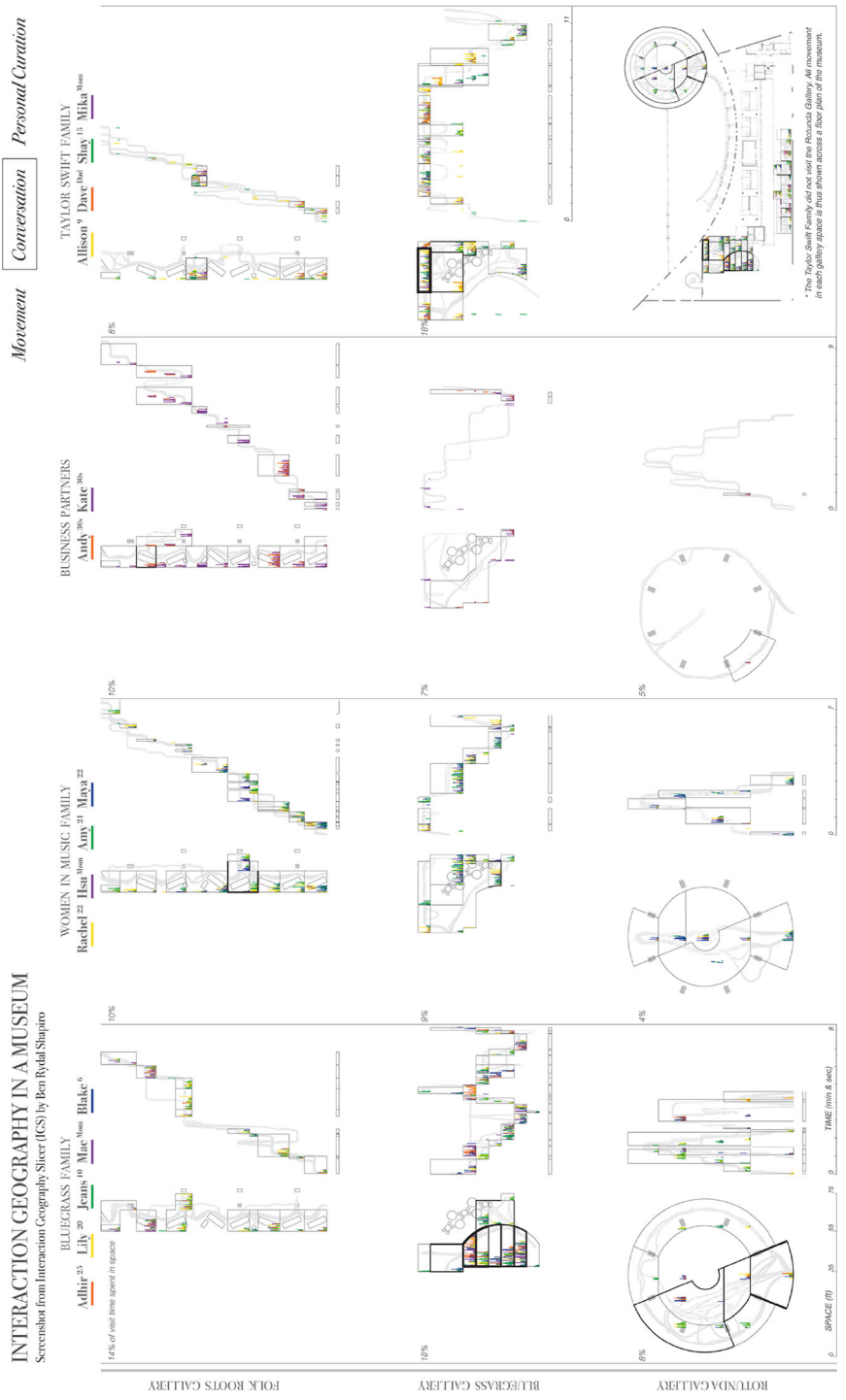


Fig. 8 Screenshot from Interaction Geography Slicer (IGS) showing conversation of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

the movement and conversation of all four visitor groups on a larger floor plan drawing of the entire museum in each figure (i.e., galleries are shown in relation to each other across the entire museum visit and floor space). These figures support many levels of reading, and like any static figure, possess many limitations. We encourage the reader to study each of these figures and draw their own findings prior to reading the following analysis of these figures.

Figures 7 and 8 advance a variety of findings. First, they show how different environmental and syntactical configurations of gallery spaces support and constrain visitors' patterns of movement and conversation. For example, the Folk Roots Gallery (1st row in each screenshot) conditions very linear ways of moving in space-time with few repeated conversational engagements for all families. In contrast, the Bluegrass and Rotunda galleries (2nd and 3rd rows) are both open-plan spaces with a wide variety of supports for sequential engagement, and accordingly, they encourage a wide variety of movement and conversation patterns across visitor groups and individuals within groups. Likewise, while the Business Partners (3rd column) exchange many conversation turns in the Folk Roots Gallery, they produce almost no conversation turns in the other two gallery spaces. Similarly, Blake makes many conversation turns in open plan spaces such as the Bluegrass and Rotunda galleries, but he makes only a single conversation turn in the Folk Roots Gallery (hence there is only one blue line in this space). Thus, the figures show how interaction geography provides ways to conceptualize and compare the ways in which the physical environment conditions the movement and conversation patterns that comprise people's engagement at exhibits and across gallery spaces.

Second, the figures show how visitors' personal and social history, prior knowledge, and relationships to one another guide them to choose particular pathways and configurations through the museum instead of others. To those who know these gallery spaces, it is clear that each visitor group's movement and conversation are distributed in ways that reflect their engagement with particular artists, instruments, and musical genres. For example, the Women in Music Family's movement and conversation often focus around exhibits featuring female artists. As they described in their post-visit interview, the family was deeply concerned with the portrayal of women in music.

Third, the figures allow analysts to ask new types of questions. For example, one can use the figures to ask how young children employ bursts of movement and conversation to attract the attention of their parents and siblings or alternatively, how young children use their families as resources for their own interest-driven learning.

Finally, the figures are static images and therefore have limitations. There are aspects of people's movement and conversations that cannot be interpreted well without more dynamic information. For example, consider the Taylor Swift Family in the Bluegrass Gallery space (4th column, 2nd row). Their movement in space-time indicates that the dad (Dave) enters the gallery 4 min after his daughter, Shay. During this time the two daughters, Allison (9 years old) and Shay (15 years old), appear to be exchanging places and conversation with one another in relation to their mother, who stands for a long time at a large record wall in the gallery space (indicated by her horizontal purple path in space-time with no change in line pattern which is similar to Adhir's path at the Hank Williams exhibit). These observations describe aspects of the family's engagement, but they do not communicate how the daughters are competing for their mother's attention. In fact, their movement and conversation are oriented toward competing about what will be talked about and what content the family will visit in the future. Thus, in some cases, these figures provide only a glimpse of a fuller interaction geography analysis, which would include more dynamic and multi-scalar ways of reading people's interaction as they move through environments.

To review, in this section we described our development and use of interaction geography to study visitor engagement in museum gallery spaces. Our discussion and analysis highlight two important themes of interaction geography.

Theme 1: Interaction geography describes, represents, and supports interpretation of interaction at a spatial and temporal scale that is intermediate in comparison to the spatial and temporal scales used by other contemporary approaches to studying conversation, interaction and movement. More specifically, interaction geography operates at a scale larger than a) interaction analysis (Jordan & Henderson, 1995), which focuses on moments of interaction in space and time, such as single conversations at museum exhibits and b) time geography (Hagerstrand, 1970), which typically focuses on people's movement across large scales of space and time (e.g., cities over days, weeks and months). However, equally important, interaction geography develops and uses methods that allow for new ways to link these differently scaled approaches to study phenomena like visitor engagement.

Theme 2: Interaction geography advances work in the social sciences, shifting analytic attention from "simulating to mapping, from simple explanations to complex observations" (Venturini et al., 2015; also see Becker, 2007). Likewise, interaction geography aims to meet provocations in the social sciences to develop what some call a geographic information systems (GIS) approach to mapping social action (Scollon, 2008) and others call a graphic anthropology (Ingold, 2007).

Extending professional insights & vision

In addition to developing and using interaction geography to study visitor engagement, we also wanted to see if and how interaction geography could be used to support the professional insights and vision (Goodwin, 1994; Gamoran Sherin and Van Es, 2009) of museum professionals working at this museum. In particular, we wanted to see if and how a computer-supported collaborative learning (CSCL) environment based on interaction geography could advance museum professionals' abilities to identify ways to design more equitable, expansive, and productive learning opportunities in museum gallery spaces. Our design and analysis of this environment drew from the rich body of CSCL literature concerning the use of tools, especially video-based tools, in forms of reflective professional practice (see Erickson, 2007; Zahn et al., 2012; Ligorio & Ritella, 2010; Johansson et al., 2017; Lymer et al., 2009; Cress et al., 2015). As stated previously, this work is part of a larger design study that, in close collaboration with our museum partners, aims to advance museum professionals' learning about ways in which design practice can create opportunities for interest-driven learning in and beyond their gallery spaces.

Two starting points informed our development and use of this CSCL environment based on interaction geography. First, visitor learning is not the only, or even primary, task of a museum's design departments (they must also design exhibits, marketing campaigns, and social media presence, for example) and learning programs and activities (e.g., tours and scavenger hunts for children) must often be designed to fit existing museum content and exhibits since the physical artifacts are traditionally designed and built first.

Second, without the information provided by new CSCL tools, museum organizations have a limited understanding of their visitors. Museum professionals rarely have opportunities to see and

understand their visitors beyond survey data (i.e. professionals at this museum had not previously seen video of visitors' interactions at this museum). This leaves them dependent on what we describe as an idealized view or model of their visitors and a passive learning model in which museum exhibits are a fixed curriculum that visitors can only succeed or fail to understand.

Our following analysis begins by showing an image of 15 museum professionals (e.g., curators, educators, exhibit designers, archivists) using the CSCL learning environment we developed during a half-day workshop. Subsequently, we use this image to describe our design of this learning environment. Finally, we suggest how this learning environment used interaction geography to disrupt conventional views of visitor engagement that museum professionals hold and then reframe these disruptions to enable museum professionals to adopt and consider (in future design decisions) a view of visitor engagement and interaction as an enacted curriculum, where learning is active, interest-driven and in the hands of visitors (Crowley & Jacobs, 2002; Schauble et al., 1997; Ellenbogen et al., 2004).

Figure 9 is a snapshot of museum professionals using the CSCL environment. In particular, the environment used the Interaction Geography Slicer (IGS) to support new forms of

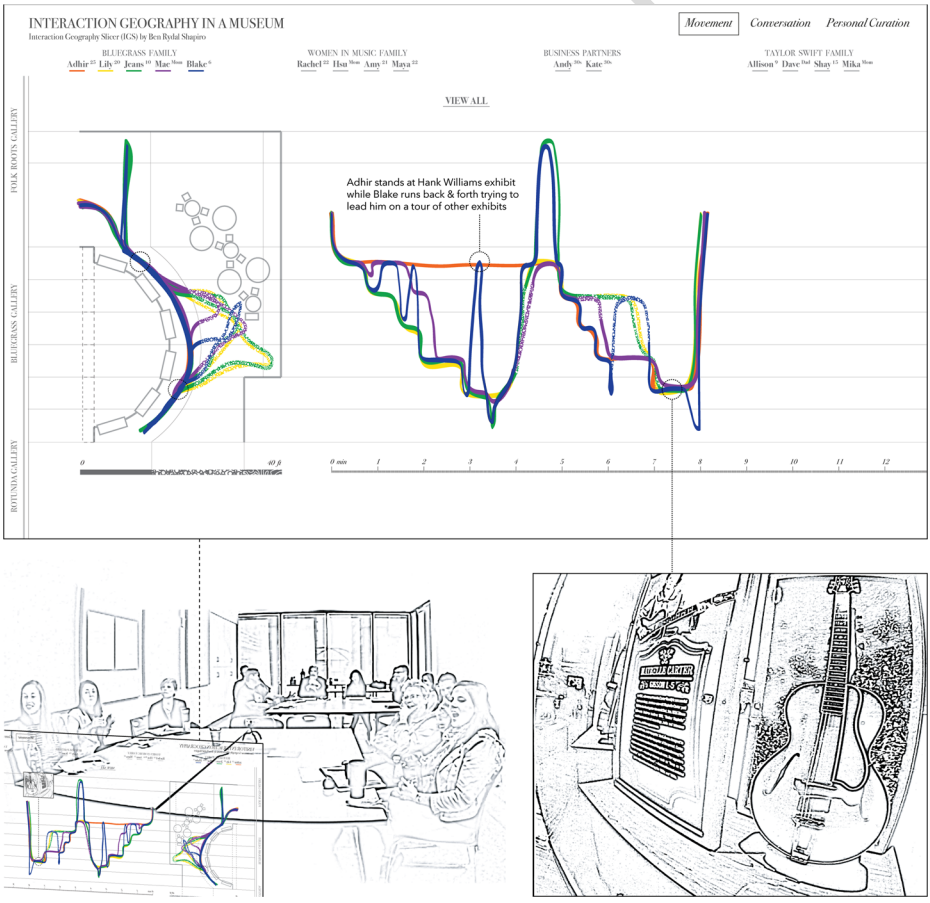


Fig. 9 Museum professionals use a computer-supported collaborative learning environment based on interaction geography and react to Blake's efforts to lead Adhir on a tour within a museum gallery space. Copyright © by Ben Rydal Shapiro. Reprinted by permission

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

interaction and multimodal analysis that in turn created opportunities for joint exploration, collaboration, and knowledge building about the ways in which 4 different visitor families/groups engaged and learned during their visit to 3 different gallery spaces. Some of the dynamic possibilities of the IGS included:

Comparisons: The IGS allowed professionals to quickly and seamlessly compare the movement, conversation and social media/technology use (which we call "personal curation") of families in either a single family/space viewing mode or a small multiple viewing mode. Figure 9 shows museum professionals studying the Bluegrass Family's movement in the single family/space viewing mode.

Layering: The IGS allowed professionals to add or remove family members or other families. For example, Fig. 9 shows museum professionals studying all members of the Bluegrass Family in a single gallery space. However, museum professionals could use the IGS to select and visualize individual family members (e.g., just Blake and Adhir) or alternatively, visualize all members of all 4 families at once in a single gallery space.

Reading Conversation: The IGS allowed professionals to read conversation in space and space-time. When visualizing conversation, museum professionals could hover over each box using a computer mouse to display and read transcribed talk of that conversation (e.g., similar to the previously highlighted text in Fig. 5).

Video & Audio: The IGS allowed professionals to select, view and listen to multi-perspective video and audio at chosen points in space or time. The IGS spatially and temporally syncs video and audio (worn by each member of each visitor group) to Mondrian Transcription. In Fig. 9, we include a screenshot from a video to show how museum professionals could click on points in space and time to play audio/video from the perspective of each family member.

In addition to the IGS, we designed instructional activities that invited participating museum professionals to explore and interpret visitor activity to make evidence-based arguments about visitor engagement and learning within museum gallery spaces. We began the half-day workshop by providing museum professionals with an hour-long introduction to concepts and methods of interaction geography, following a format similar to the first part of this article. In this introduction, we intended to teach museum professionals about a) ways of reading space-time, b) concepts and methods of interaction geography such as using interactive Mondrian Transcripts to find and explore engagement contours, c) how to use the IGS as a tool (e.g., to watch video, listen to audio and read conversation), and d) how to use multi-person, mobile video recordings to make evidence-based arguments about visitor engagement and learning (e.g., to compare ambulatory sequences that demonstrated strong or weak alignments between exhibit content and family members' sensemaking while in gallery spaces). Following this introduction, museum professionals split into two teams (organized primarily by department) to conduct their own analysis using the IGS. Team analysis lasted for approximately two hours. Finally, museum professionals reconvened for approximately one hour to share findings and questions, and to discuss opportunities for using interaction geography in future museum design.

We observed three ways that this CSCL environment based on interaction geography extended the professional insights and vision of museum professionals during the half-day session. A full analysis is beyond the scope of this paper, but we draw from our own

interaction analysis of video and audio recordings of the session, our field notes and understanding of the museum setting from longer-term ethnographic analysis, and an analysis of post-session surveys that elicited feedback about the CSCL environment from museum professionals. It is important to note that the departmental backgrounds of museum professionals framed the ways in which they used the CSCL environment to select data, make arguments about visitor engagement and learning, and engage in particular types of practices. For example, museum educators simultaneously used space-time views, video, and transcripts of visitor conversations to focus on the ways in which visitors produced engagement through their movement, conversation, and relationships with other family or group members. In contrast, exhibit designers rarely made use of video and, instead, used floor plan views and transcripts separately to focus on how particular exhibit and gallery layouts influenced visitors' activities. These differences highlight departmental interests and work practices.

Seeing Visitor Engagement and Learning in New Ways: Museum professionals were able to see and study visitor engagement and learning in innovative ways. Previously, many participants viewed young children's erratic movements in museum gallery spaces as childish behavior that prevented engagement and learning. When first confronted with Blake's rapid movements in the Bluegrass gallery space (e.g., their reactions/expressions are shown in Fig. 9), few believed that he could possibly be learning. Some expressed concern that his erratic movement might even be undermining the intended design of exhibits by distracting other members of his family. However, the collaborative use of the IGS provided opportunities for the professionals to unpack and describe Blake's (and other children's) movement and conversation patterns as drivers of engagement contours that supported forms of learning as children moved. Following Blake in the video corpus of recordings turned out to be revealing for museum professionals. After understanding how Blake finally managed to lead Adhir on a tour of Bluegrass musicians, the professionals explored Blake's activity in a different gallery space, the Rotunda Gallery. Here, museum professionals discovered how Blake first failed to get an answer to a question that he posed to Adhir as to who co-starred in the 1970's action/comedy film *Smokey and the Bandit*. Immediately afterward, Blake ran to another gallery space to find and get the correct answer from his brother Jeans. Subsequently, Blake then raced back to Adhir to inform him that it was Jerry Reed, a Grammy-winner country artist, that co-starred in the film. What initially seemed like off-task or disruptive behavior, eventually became recognized as a form of "learning on the move", one that museum professionals now hoped to be able to support (Taylor, 2017; Marin, 2013; Taylor & Hall, 2013).

We believe these findings were surprising for participating museum professionals because they disrupted their beliefs and perceptions about visitor activity. The ability to observe and study children's interaction geographies across gallery spaces, and to describe these phenomena as drivers of engagement and interest-driven learning, led to a significant shift in the professional insights and vision of some participants. They began to challenge idealized models of museum visitors as relatively passive consumers of intended designs and instead, to see and discuss museum visitors as active producers or curators of their own interest-driven engagement and learning. There were even jokes about hiring Blake as a museum ambassador for Bluegrass music.

Asking New Research Questions: Museum professionals used the CSCL environment to ask questions currently important within museum studies and to ask new types of

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

questions. They began to use the environment to describe, represent, and interpret the ways in which adults coordinated young children's attention and observation, not only at single exhibits, as is typically the case in museum studies, but also as returns or forms of linking across multiple exhibits and gallery spaces. For example, the professionals studied and compared how parents used their movement and conversation to manage their children's engagement and learning across gallery spaces or at particular exhibits and at particular times within gallery spaces. Moreover, museum professionals were able to ask new questions such as how young children manage their families as interpretive resources in and across museum gallery spaces. For instance, the professionals discovered that young children often went to great lengths to explore gallery spaces independently, to gather or retrieve information about exhibit content, and to share what they found with other family members for a variety of purposes. Some children did this in order to physically move adults or parents to other parts of the museum. Other children did so to teach adults about what they had found, and to elicit adults' conversation about exhibit content related to the child's personal interests, or to what the child believed would interest adults. Finally, museum professionals were able to utilize language of interaction geography to, for instance, classify moments of peak engagement or engagement contours and how these moments often revealed trajectories of interest-driven learning within their gallery spaces.

Making Evidence Based Decisions: Many museum professionals felt that, with further development, the CSCL environment along with concepts and methods of interaction geography could provide meaningful ways to support evidence-based design decisions in the museum and to encourage collaborative design across museum departments. In particular, they suggested that this work could provide a way not only to learn about their visitors but also to gather evidence on visitor activity that could inform future, more expansive, and equitable design decisions regarding museum learning programs and activities. They also suggested that the visual and interactive nature of our work could provide ways for different museum departments to work together in new ways. As one museum educator explained in the post-survey:

I recall the productive cross-department conversation about visitor behavior, engagement, learning. We seldom (never?) have the opportunity to discuss visitor experience in the gallery—with our content—across departments. I also enjoyed and benefited from the visitor conversations in relation to specific space and artifacts—good to "see" the exhibit through their eyes and mind rather than assume their view, takeaways, paths, etc.

Conclusion, limitations & next steps

We began this paper by illustrating the significant and unmet need to develop integrative approaches to study learning that simultaneously consider learning in relation to the physical environment, people's interaction with one another, and people's movement. Subsequently, we introduced interaction geography, a new approach to describing, representing, and interpreting people's interaction. We argued that interaction geography provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings.

We illustrated this approach with data from a museum, but we consider interaction geography to be general purpose and applicable to many other settings including more formal learning settings. For instance, interaction geography can be used in classroom and school settings to study the alignment of space and pedagogy (Monahan, 2002; Cleveland, 2009) and to address research challenges such as how to "observe 12 children simultaneously playing in up to six different areas in the preschool classroom (e.g., blocks center, manipulative center) or on the playground (e.g., bikes, climbing structure)" (Rowe & Neitzel, 2010, pg. 172). Similarly, interaction geography can be extended to outdoor spaces to provide a new framework for the design and analysis of place-based or mobility centered learning activities (see Hall et al., 2017; Taylor, 2017). Moreover, with respect to the CSCL community, interaction geography provides new ways to understand group interactions over time in technology-mediated environments (Stahl, 2017) and to incorporate multi-perspective audio/video recordings in reflective professional practice.

We expect that ongoing technical and conceptual development of interaction geography can support new collaborations across the fields of education, information visualization, architecture, and the arts. Collaborations like these are increasingly becoming central as researchers and practitioners explore opportunities and potential for learning in people's everyday lives. We conclude by pointing out three limitations of this work and by delineating potential next steps for expanding this work in collaboration with others.

First, our report is restricted to an exploratory study within a particular type of setting for informal learning. As we define and increase the utility of interaction geography, we will need to advance concepts and methods discussed in this paper to other types of settings and institutional contexts. We are especially interested in involving professional practitioners in in-depth analyses of interaction geography. They are in the best position to make sense of detailed traces of interaction and to use that information to enhance opportunities and contexts for learning.

Second, important questions concerning the generalizability of methods of interaction geography are as yet to be explored. Of particular interest is the ways in which other researchers, educators, and designers might use and advance these methods in a range of contexts. Mondrian Transcription and the Interaction Geography Slicer described in this article were intended to serve as artifacts to communicate interaction geography to a broad audience and to guide future computational development of both qualitative transcription software and quantitative information visualization and visual analytics software. For example, current versions of the IGS are written in Java, the Processing Programming Language (Reas & Fry, 2007) and Unfolding Maps Library (Nagel et al., 2013) and support multiple 2D & 3D representational views, floor plan or map rotation to explore patterns in ambulatory sequences, engagement contours, and aggregate meshworks of visitor engagement (addressing questions as to whether, for example, interpretations in one floor plan view hold up over changes in orientation and scale in other views), along with ways for users to layer different digital base maps or floor plans underneath people's activity (see Shapiro et al., 2017 and Shapiro, 2017b for adaptations of the IGS to visualize New York City's controversial Stop-and-Frisk Program and to advance social studies teaching). With further support, we hope to make these methods and software widely available to others working in a variety of settings and to develop custom methods and software tailored for particular types of settings and institutions. Further information on our progress and development will be available at https://benrydal.com. We welcome partnerships and collaborations with other institutions, researchers, designers, and practitioners to advance these efforts.

Third, there are significant ethical considerations that require attention in interaction geography. Our work was made possible by many generous families/people who volunteered their time to participate in this research—at the end of their visits, nearly all families/groups went out of their way to report that they thoroughly enjoyed participating in this research and found it to be unobtrusive (e.g., most forgot they were wearing small cameras as necklaces within a few minutes). However, additional thought needs to be given as to how and when to seek permission from participants, and how that request may affect their interactions. In our future work we will explore issues regarding informed consent (from the perspective of ethical research practice) and fair use of media in public or private spaces (from a perspective on intellectual property). These issues are beyond the scope of this article, but remain a serious concern.

Acknowledgements This work is made possible by wonderful collaborations with our museum partners, many generous families and visitors participating in this research, the Space, Learning & Mobility Lab at Vanderbilt University, Leona Schauble, and the National Science Foundation, who supports this work through the Bridging Learning in Urban Extended Spaces (BLUES) Project. In addition, we would like to thank Brette Garner, Lara Heiberger, Danielle Keifert, and others from the Interaction Analysis Lab at Vanderbilt, Mark Shapiro and the Processing Foundation for software development advice and inspiration, and Kären Wieckert, and Barbara and Steve Magie for important and timely feedback throughout this project.

References

Azevedo, F. S. (2013). The Tailored Practice of Hobbies and Its Implication for the Design of Interest Driven Learning Environments. *The Journal of the Learning Sciences, 22*(3), 462–510.

Becker, H. (2007). *Telling About Society*. Chicago: University of Chicago Press.

Cleveland, B. (2009). Equitable pedagogical spaces: Teaching and learning environments that support personalisation of the learning experience. *Critical and Creative Thinking: The Australasian Journal of Philosophy in Education, 17*(2), 59–76.

Cleveland, B., & Fisher, K. (2013). The evaluation of physical learning environments: a critical review of the literature. *Learning Environments Research, 17*, 1–28.

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

Cress, U. (2008). The need for considering multilevel analysis in CSCL research—An appeal for the use of more advanced statistical methods. *International Journal of Computer-Supported Collaborative Learning, 3*(1), 69–84.

Cress, U., Stahl, G., Ludvigsen, S., & Law, N. (2015). The core features of CSCL: Social situation, collaborative knowledge processes and their design. *International Journal of Computer-Supported Collaborative Learning, 10*(2), 109–116.

Cresswell, T. (2010). Towards a politics of mobility. *Environment and planning D: society and space, 28*(1), 17–31.

Crowley, K., & Jacobs, M. (2002). Building islands of expertise in everyday family activity. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 333–356). Mahwah: Lawrence Erlbaum Associates.

Davidsen, J., & Ryberg, T. (2017). "This is the size of one meter": Children's bodily-material collaboration. *International Journal of Computer-Supported Collaborative Learning, 12*(1), 65–90.

Derry, S. J., Pea, R., Barron, B., Engle, R., Erickson, F., Goldman, R., Hall, R., Koschmann, T., Lemke, J., Sherin, M., & Sherin, B. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *Journal of the Learning Sciences, 19*, 1–51.

Ellenbogen, K. M., Luke, J. J., & Dierking, L. D. (2004). Family learning research in museums: An emerging disciplinary matrix? *Science Education, 88*(S1), S48–S58.

Erickson, F. (2004). *Talk and social theory: Ecologies of speaking and listening in everyday life*. Cambridge: Polity.

Erickson, F. (2007). Ways of seeing video: Towards a phenomenology of viewing minimally edited footage. In R. Goldman, R. Pea, S. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 145–155). 732). Mahwah: Lawrence Erlbaum Associate Publishers.

Escott, C., Merritt, G., & MacEwan, W. (2004). *I saw the light: The story of Hank Williams*. New York: Back Bay Books.

Flood, V. J., Neff, M., & Abrahamson, D. (2015). Boundary interactions: Resolving interdisciplinary collaboration challenges using digitized embodied performances. In *CSCL'15: Proceedings of the 11th International Conference for Computer Supported Collaborative Learning* (Vol. 1, pp. 94–100). Gothenburg: The International Society of the Learning Sciences.

Gamoran Sherin, M., & Van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education, 60*(1), 20–37.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633.

Hagerstrand, T. (1970). What about people in regional science? *Papers in Regional Science, 24*(1), 6–21.

Hall, R., & Stevens, R. (2015). Interaction analysis approaches to knowledge in use. In A. A. diSessa, M. Levin, & J. S. Brown (Eds.), *Knowledge and interaction: A synthetic agenda for the learning sciences* (pp. 72–108). New York: Routledge.

Hall, R., Marin, A., Taylor, K. H., Silvis, D., Pinkhard, N. & Enyedy, N. (2017). Can we use location-aware tools and practices to create a new genre of learning on the move (LoM)? Discussion Session at the 47th Annual Meeting of the Jean Piaget Society, San Francisco.

Ingold, T. (2007). *Lines: A Brief History*. London: Routledge.

Ito, M., et al. (2009). *Hanging Out, Messing Around, and Geeking Out: Kids Living and Learning with New Media*. Cambridge: MIT Press.

Johansson, E., Lindwall, O., & Rystedt, H. (2017). Experiences, appearances, and interprofessional training: The instructional use of video in post-simulation debriefings. *International Journal of Computer-Supported Collaborative Learning, 12*(1), 91–112.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*(1), 39–103.

Kendon, A. (1990). Spatial organization in social encounters: The F-formation system. Conducting interaction: Patterns of behavior in focused encounters, pp. 209–238.

Kwan, M., & Lee, J. (2003). Geovisualization of Human Activity Patterns Using 3D GIS: A Time-Geographic Approach. In M. F. Goodchild & D. G. Janelle (Eds.), *Spatially Integrated Social Science: Examples in Best Practice*, Chapter 3. Oxford: Oxford University Press.

Lave, J., Murtaugh, M., & de la Rocha, O. (1984). The dialectics of arithmetic in grocery shopping. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 67–94). Cambridge: Cambridge University Press.

Leander, K. (2002). Locating Latanya: The situated production of identity artifacts in classroom interaction. *Research in the Teaching of English, 37*, 198–250. Q9

Lemke, J. L. (2000). Across the scales of time: Artifacts, activities, and meanings in ecosocial systems. *Mind, Culture, and Activity, 7*(4), 273–290.

Ligorio, M. B., & Ritella, G. (2010). The collaborative construction of chronotopes during computer-supported collaborative professional tasks. *International Journal of Computer-Supported Collaborative Learning, 5*(4), 433–452.

Lymer, G., Ivarsson, J., & Lindwall, O. (2009). Contrasting the use of tools for presentation and critique: Some 779 cases from architectural education. *International Journal of Computer-Supported Collaborative Learning*, 780, *4*(4), 423–444. Q10

Ma, J. Y., & Munter, C. (2014). The Spatial Production of Learning Opportunities in Skateboard Parks. *Mind, Culture, and Activity, 21*(3), 238–258.

Monahan, T. (2002). Flexible space and built pedagogy: Emerging IT embodiments. *Inventio, 4*(1), 1–19.

Marin, Ananda M. (2013). Learning to Attend and Observe: Parent-child Meaning Making in the Natural World. Ph.D. Dissertation. Northwestern University.

Nagel, T., Klerkx, J., Moere, A. V., and Duval, E. (2013). Unfolding–a library for interactive maps. In *Human Factors in Computing and Informatics* (pp. 497–513). Springer Berlin Heidelberg. Q11

Peponis, J., Zimring, C., & Choi, Y. K. (1990). Finding the Building in Wayfinding. *Environment and Behavior, 22*(5), 555–590.

Peppler, K. (Ed.). (2017). *Encyclopedia of out-of-school learning (Two-volume set)*. Los Angeles: Sage Publications.

Reas, Casey and Fry, Ben. (2007). Processing: a programming handbook for visual designers and artists. Mit Press. Q12

Rowe, D., & Neitzel, C. (2010). Interest and Agency in 2 and 3 Year Olds' Participation in Emergent Writing. *Reading Research Quarterly, 45*(2), 169–195.

Schauble, L., Leinhardt, G., & Martin, L. (1997). A framework for organizing a cumulative research agenda in informal learning contexts. *Journal of Museum Education, 22*, 3–7.

Scollon, R., & Scollon, S. W. (2003). *Discourses in place: Language in the material world*. New York: Routledge.

Scott-Webber, L. (2004). *InSync: Environment Behavior Research and the Design of Learning Spaces*. Ann Arbor: Society for College and University Planning.

JrnlID 11412_ArtID 9264_Proof# 1 - 13/11/2017

Shapiro, B.R. (2017a). Using Space Time Visualization in Learning Environment Design. In Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '17). ACM, Denver, CO, USA (pp. 178–183).

Shapiro, B.R. (2017b). Exploring the Use of Interaction Geography to Advance Post-Occupancy Evaluation. In *Proceedings of the 1st annual Transitions Symposium*. The University of Melbourne's Innovative Learning Environments and Teacher Change (ILETC) Project, 2016–2019. Melbourne School of Design, University of Melbourne.

Shapiro, B.R., and Hall, R. (2017). Making Engagement Visible: The Use of Mondrian Transcripts in a Museum. In *CSCL'17: Proceedings of the 12th International Conference for Computer Supported Collaborative Learning*, (Vol. 1, pp. 33–40). Philadelphia: International Society of the Learning Sciences.

Shapiro, B.R. & Pearman II, Francis A. (2017). Using the Interaction Geography Slicer to Visualize New York City Stop & Frisk. In *Proceedings of the IEEE VIS 2017 Arts Program, VISAP'17*. Phoenix, AZ.

Sheller, M., & Urry, J. (2006). The new mobilities paradigm. *Environment and Planning A, 38*(2), 207–226.

Stahl, G. (2017). Group practices: A new way of viewing CSCL. *International Journal of Computer-Supported Collaborative Learning*, 12(1).

Stahl, G., Koschmann, T., & Suthers, D. (2006). *Computer-supported collaborative learning: An historical perspective*. Cambridge: Cambridge Handbook of the Learning Sciences.

Stahl, G., Ludvigsen, S., Law, N., & Cress, U. (2014). CSCL artifacts. *International Journal of Computer-Supported Collaborative Learning., 9*(3), 237–245.

Stasko, J., Görg, C., & Liu, Z. (2008). Jigsaw: Supporting Investigative Analysis through Interactive Visualization. *Information Visualization, 7*(2), 118–132.

Steier, R. (2014). Posing the question: Visitor posing as embodied interpretation in an art museum. *Mind, Culture, and Activity, 21*(2), 148–170.

Stevens, R., & Hall, R. (1997). Seeing the Tornado: how VideoTraces mediate visitor understandings of (natural?) spectacles in a science museum. *Science Education, 81*(6), 735–747.

Suthers, D. D., Dwyer, N., Medina, R., & Vatrapu, R. (2010). A framework for conceptualizing, representing, and analyzing distributed interaction. *International Journal of Computer-Supported Collaborative Learning, 5*(1), 5–42.

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*(0), 1–42.

Tzortzi, K. (2014). Movement in museums: mediating between museum intent and visitor experience. *Museum Management and Curatorship, 29*(4), 327–348.

Venturini, T., Jensen, P., & Latour, B. (2015). Fill in the Gap: A New Alliance for Social and Natural Sciences. *Journal of Artificial Societies and Social Simulation, 18*(2), 11.

Wineman, J., Peponis, J., & Dalton, R. (2006). Exploring, Engaging, Understanding in Museums. Paper presented at the Space Syntax and Spatial Cognition Workshop: Spatial Cognition '06, Universität Bremen, Bremen.

Zahn, C., Krauskopf, K., Hesse, F. W., & Pea, R. (2012). How to improve collaborative learning with video tools in the classroom? Social vs. cognitive guidance for student teams. *International Journal of Computer-Supported Collaborative Learning, 7*(2), 259–284.

Zimring, C. M., & Reizenstein, J. E. (1980). Post-occupancy evaluation: An overview. *Environment and Behavior, 12*, 429–450.

Q13