Journal of Research on Technology in Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ujrt20

Classroom interaction geography: visualizing space & time in classroom interaction

Ben Rydal Shapiro & Brette Garner

To cite this article: Ben Rydal Shapiro & Brette Garner (2021): Classroom interaction geography: visualizing space & time in classroom interaction, Journal of Research on Technology in Education, DOI: 10.1080/15391523.2021.1927265

To link to this article: https://doi.org/10.1080/15391523.2021.1927265

Published online: 23 Jun 2021.

JOURNAL OF RESEARCH ON TECHNOLOGY IN EDUCATION
https://doi.org/10.1080/15391523.2021.1927265

Classroom interaction geography: visualizing space & time in classroom interaction

Ben Rydal Shapiro[a] and Brette Garner[b]

[a]Georgia State University, Atlanta, GA, USA; [b]University of Denver, Denver, CO, USA

ABSTRACT
Methods to transcribe and represent classroom video data are central to studying teaching and learning in classrooms. However, current methods focus on encoding and representing data over time, not space. In this paper, we demonstrate the value of a new methodological approach called interaction geography to transcribe and interactively visualize classroom video data over space and time. We use interaction geography to illustrate classroom participation patterns in two case studies from teacher education research that, until now, have been challenging to see. Findings characterize strengths, limitations, and next steps to expand interaction geography in classroom research and suggest new questions to consider when encoding and representing classroom research data over space and time.

ARTICLE HISTORY
Received 14 December 2020
Revised 11 March 2021
Accepted 4 May 2021

KEYWORDS
Teacher education; qualitative methods; video applications; information visualization

Methods to transcribe and represent classroom video data are central to studying teaching and learning in classrooms. For example, video-based methods have been critically important to characterizing patterns in teachers' questioning such as Initiation-Response-Evaluation, funneling, and focusing (Herbel-Eisenmann & Breyfogle, 2005; Mehan, 1979), strategies such as re-voicing (O'Connor & Michaels, 1993), and processes such as teacher noticing (Sherin et al., 2011). However, current methods focus on encoding and representing data over time, not space. As a result, it remains difficult to ask and answer questions about classroom interaction that require coordinated analyses of space and time: How does teacher and student talk vary in different areas of a classroom throughout a lesson? How does teachers' movement across a classroom create discursive spaces for students to explain their thinking during class discussions? Where and when do teachers address a class during a lesson? How do students' participation patterns shift as a result of a teacher's proximity or the physical design of a classroom?

This paper illustrates the value of a new methodological approach, called interaction geography, to transcribe and interactively visualize classroom video data over space and time. Interaction geography encompasses tools that allow researchers to transcribe and interactively visualize location, conversation, and audiovisual data over space and time (Shapiro et al., 2017). These tools are open-source and available at the following links: Mondrian Transcription (https://www.benrydal.com/software/mondrian-transcription) and the Interaction Geography Slicer (https://www.benrydal.com/software/igs). We use interaction geography in this paper to illustrate classroom participation patterns in two case studies from teacher education that, until now, have been challenging to see. Our analysis demonstrates how classroom researchers can use interaction geography to quickly identify aggregate patterns about how much, where, and when teachers and students speak throughout a lesson and also to selectively study important moments from classroom video datasets that are not easily visible with existing methods.

We begin by reviewing situative perspectives on teaching practice and the methods that ground our work. Next, we use interaction geography to revisit a classic case from the work of

CONTACT Ben Rydal Shapiro bshapiro@gsu.edu Department of Learning Sciences, Georgia State University, Atlanta, GA 30303, USA

Deborah Ball known colloquially as "Sean Numbers" (Ball, 1993). We use three figures to progressively demonstrate tools of interaction geography and how these tools support new insight into this lesson excerpt, specifically analyzing how the teacher used her movement within the classroom to delegate authority to students. In Case 2, we revisit a complete classroom science lesson in the U.S. from The Third International Mathematics and Science Study (TIMSS) 1999 Video Study (see Stigler & Hiebert, 2009). We unpack two figures to show how interaction geography can be used to explore larger classroom video datasets.

We conclude by discussing strengths, limitations, and next steps to expand interaction geography in classroom research and suggest new questions to consider when encoding and representing classroom research data over space and time. We also emphasize the importance of advancing discussions and protocols that foreground the ethical collection and use of data about teachers and students when developing and using new visualization technologies in classrooms. In summary, this paper illustrates the value of a new video-based methodological approach that can better account for both the spatial and temporal dimensions of classroom interaction.

Theoretical framework

We draw on an established body of research that illustrates how teaching is a culturally and historically situated activity, constituted in relation to learners and communities (Cazden, 2001; Lampert & Cobb, 2003; Lave & Wenger, 1991; Ma & Singer-Gabella, 2011). This literature emphasizes the social dimensions of teaching, viewing student learning as an interactional accomplishment between teachers, students, and the institutional settings in which they work (Cohen, 2011; Greeno, 1998).

Scholars in this tradition have historically used methods such as interaction analysis to describe how patterns of talk and activity are organized during classroom interaction over time (see Cazden, 2001; Erickson et al., 2017; Jordan & Henderson, 1995; van Es & Sherin, 2002). Other studies have analyzed broader patterns of interaction, including social and sociomathematical norms (Yackel & Cobb, 1996) and collaborative groupwork structures (Cohen & Lotan, 2014), noting how classroom communities develop and change over time. In additional analyses, researchers have looked across classrooms to understand how teachers maintain or lower cognitive demand as they implement lessons (Stein et al., 1996; Wilhelm, 2014). Studies such as these highlight important features of classroom discourse that are consequential for student learning. However, analyses in this tradition typically overlook the spatial aspects of classroom interaction beyond visual displays (e.g., chalkboards) or the physical arrangement of desks (e.g., in rows or small groups).

More recently, researchers have sought to include space and movement in situative studies of classroom interaction. Some have introduced concepts that foreground the spatial dimension of classroom interaction and teaching. For example, concepts such as *built pedagogy* (Monahan, 2005) and *equitable pedagogical spaces* (Cleveland, 2009) suggest that teachers' use of space is a critical, but often overlooked, aspect of teaching practice. Likewise, Lim et al. (2012) argue that *spatial pedagogies* shape teachers' implementation of lessons — which impacts students' participation and learning opportunities — even though teachers may not be fully conscious of their own spatial pedagogy.

Others have used particular representations to foreground the spatial dimension of classroom interaction in various ways. For example, Leander (2002) used f-formation diagrams (see Kendon, 1990) to show how the spatial positioning of teachers and students during very short sequences of classroom interaction can contribute to students' identity construction. Likewise, to make teachers more aware of the spatial dimensions of instruction, Martinez-Maldonado et al. (2020) have prompted teachers to examine and reflect on "heat map" representations of their lessons — classroom floor plans with an overlay of the teacher's and students' movements as points or positions at moments in time, highlighting areas of relatively high and low traffic. They argue that such representations can support more intentional and responsive pedagogical practices.

While f-formation diagrams and heat maps draw attention to spatial aspects of instruction — and may thereby support teachers' reflection — a key limitation of these representations is that they do not show classroom discourse and do not adequately represent time.

Still others have begun to develop frameworks to characterize different ways the temporal dimension of classroom interaction influences teaching practice. For example, Ehrenfeld and Horn (2020) have developed a framework to conceptualize teachers' monitoring routines during groupwork, noting teachers' movements around the classroom and their interactions with small groups of students over time. They identify five aspects of teachers' interactions with groups — the initiation of the interaction, conversational entry, focus of the conversation, how teachers exit the conversation, and the overall participation pattern — thereby providing one way to connect teachers' spatial movements within the classroom to the discursive patterns of their conversations with student groups. While Ehrenfeld and Horn's representation highlights how teachers' monitoring patterns unfold over time, it obscures some of the spatial details of teachers' movement.

Collectively, this recent work highlights the value of incorporating the spatial and temporal dimensions of classroom interaction into situative analyses of teaching. However, these studies each explicitly highlight the lack of methods — specifically visual methods — that allow researchers to represent and analyze both the sequential and spatial aspects of classroom interaction simultaneously. In particular, there is a need for methods that show teachers' and students' movement over time, link their movement with classroom discourse, integrate different types of classroom data (e.g., indoor location data, conversation, audio/video etc.), and support the development of a broader range of concepts to describe the spatial dimension of classroom interaction and its role in teaching practice. Accordingly, we address this gap by incorporating interaction geography into situated analyses of classroom interaction.

Method

Method & case selection

We use a case study approach (Yin, 2009) to explore how interaction geography supports new ways of seeing classroom interaction over space and time. Like Stake (1995), we understand the case study as a method that is context-sensitive and oriented to generating new questions and discovering meaning inductively. We selected two cases from teacher education that are familiar to a broad audience of teachers, educators, and researchers (see Ball et al., 2014; Stigler & Hiebert, 2009) and differ in ways that allow us to characterize particular strengths and limitations of interaction geography for classroom research.

Case 1 (Sean Numbers) is an excerpt from a third-grade math lesson taught by Deborah Ball (see Mathematics Teaching and Learning to Teach (MTLT), University of Michigan, 2010). In the days leading up to this lesson, the class had been studying even and odd numbers. The focal 7-minute excerpt began when one student, Sean, offered a conjecture that the number 6 is "both even and odd." He argued that 6 could be even, since it is made up of two threes, but that it could also be odd because it is made up of three twos. Subsequently, the class debated Sean's conjecture, and multiple students illustrated their points at the chalkboard. Ultimately, Ball and her students defined 6 as a "Sean Number," which is any number that has "an odd number of groups of two," such as 6, 10, 14, and so on (Ball, 1993, p. 387). Notably, the original video data was collected in a way that identified each individual student as well as the teacher. The short excerpt and detailed transcript also allows for a closer analysis of interactions in this case.

Case 2 is a 56-minute classroom lesson from The Third International Mathematics and Science Study (TIMSS) Video Study (1999). The TIMSS 1999 Video Study recorded eighth-grade science and mathematics instruction across seven countries. The study also made available a public repository of videos for use by the general public and research community. The particular case we selected from this repository of videos is an eighth-grade science lesson in the United States. There were 25 students in the class, and this was the final lesson in a sequence of 20 lessons on meteorology. During the lesson, students collaborated at their tables as teams of meteorologists to create a national weather map. Notably, the teacher used a number of different pedagogical strategies during this lesson to support class discussion and student collaboration. In contrast to Case 1, the original video data from this case did not identify students; instead, turns of talk were attributed to either the teacher or more aggregated student categories (e.g., the same individual as the last student to speak or a different individual from the last student to speak). Thus, the length of this case and the coding of speakers offer a broad, whole-class perspective on classroom interaction.

Data & analysis

We use interaction geography to analyze the original video data and existing conversation transcripts in new ways. Interaction geography integrates a geographical perspective called time geography (Hagerstrand, 1970) with qualitative methods of interaction analysis used to analyze video data (Jordan & Henderson, 1995). Interaction geography consists of *Mondrian transcription*, a process supported by software to transcribe video data about people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS)*, a dynamic visualization tool that allows for exploratory analyses of people's movement and conversation in relation to audio and video.

For each case, we used Mondrian Transcription software to trace teacher and student movement over a floor plan representation of the classroom space. This generated a text file of positioning data for each individual — essentially, a transcript of their movement. We then added transcripts of classroom conversations, with turns of talk coded by speaker and time of the beginning of the utterance. While many tools exist to transcribe conversation, Mondrian Transcription is one of the first examples of a tool to transcribe movement alongside conversation. We then used the IGS to synchronize the movement and conversation transcripts with the video data, allowing us to visually explore each case in new ways. In the following section, we illustrate this methodological approach and offer new avenues for exploration by classroom researchers, teachers, and educators.

Results

Case 1: Revisiting sean numbers

Transcribing teacher movement over space and time

Figure 1 shows the teacher's movement during this approximately 7-minute excerpt of classroom interaction over a *floor plan view* and a *space-time view*. The left part of the figure is the *floor plan view*; it shows a simplified floor plan of a classroom. In other words, readers are looking down on four groups of desks (with four or five desks in each group) and a chalkboard that extends the length of the classroom, on the right. There are seventeen students and one teacher seated at desks, depicted as ovals. Five individuals — Sean, Mei, Nathan, Cassandra, and the teacher — are highlighted in color; all other students are shown in gray. In addition, the purple line represents the teacher's movement across the classroom, indicating where she walks during the discussion.

The right part of the figure is a *space-time view*, which reveals the teacher's movement over a timeline, in minutes and seconds, along the horizontal axis. The vertical axis in the space-time view corresponds to the vertical dimension on the floor plan. We have annotated the figure to help read the space-time view. The beginning of the space-time view (0:00-2:30) shows a flat horizontal line, which indicates that the teacher remained seated at the desk in the lower right of the floor plan. The next segment of the space-time view (2:30-4:45) shows the teacher standing

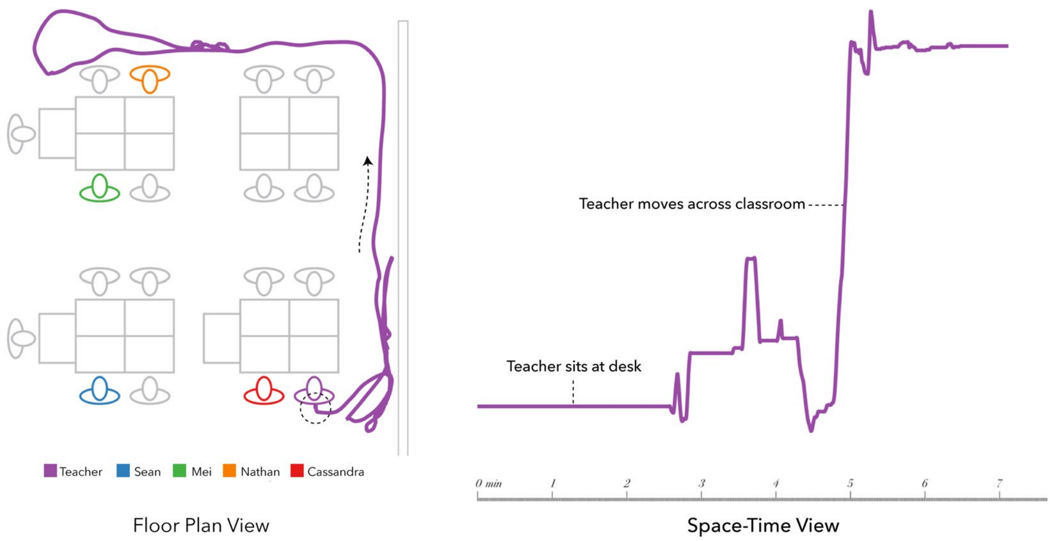

Figure 1. Teacher movement over space and space-time during a seven-minute classroom discussion from the Sean Numbers case. On the left, a floor plan view shows where the teacher (purple path) moves, as well as the positioning of students and furniture within the classroom. On the right, the teacher's movement is extended over space-time, with the vertical axis corresponding to the vertical dimension on the floor plan (Data used with special permission from Mathematics Teaching and Learning to Teach, University of Michigan).

near the chalkboard, moving slightly, near the lower right corner of the floor plan. From approximately 4:45-5:15 in the space-time view, a line extends upwards; this indicates the teacher's path across the classroom, corresponding with the dotted arrow marked on the floor plan. During these 30 seconds, she walked along the chalkboard, traversing the classroom (thus her movement extends from the bottom to top of both views). For the remainder of the discussion, the teacher stayed on that side of the classroom.

This representation supports detailed analysis of the teacher's movement. For example, the floor plan view in Figure 1 shows that the teacher did not approach the group in the lower left corner during this sequence of interaction; this raises questions about how much students at that table engaged in the class discussion. Likewise, the figure highlights repeated patterns of the teacher's movement near the chalkboard (overlapping lines) that indicate pacing patterns; these may indicate how the teacher addressed the class. Moreover, the space-time view highlights how the teacher began this discussion near the chalkboard and at the front of the classroom, but gradually moved across the classroom to stand toward the back.

Together, both views encourage questions: How did students' participation patterns shift as a result of the teacher's proximity to different groups? They also help to find and highlight potentially important moments during this interaction, such as when the teacher's movement patterns changed direction, shifted considerably, or when she visited the same area of space in the classroom multiple times. Notably, answering these types of questions and identifying potentially important moments of interaction by studying a teacher's movement are challenging through conventional representations, such as video or heat maps of positioning data. In short, Figure 1 shows a representation that allows more detailed analysis of moments of a teacher's movement, without losing sight of her overall movement within the classroom.

Mondrian transcription: layering discourse and movement

Building on the representation of movement presented in Figure 1, Figure 2 uses *Mondrian Transcription* to represent both movement and conversation over space and time. The figure is composed of six Mondrian transcripts, each highlighting different participants. Figure 2A superimposes the teacher's movement (in purple, as shown previously) over the movement of four

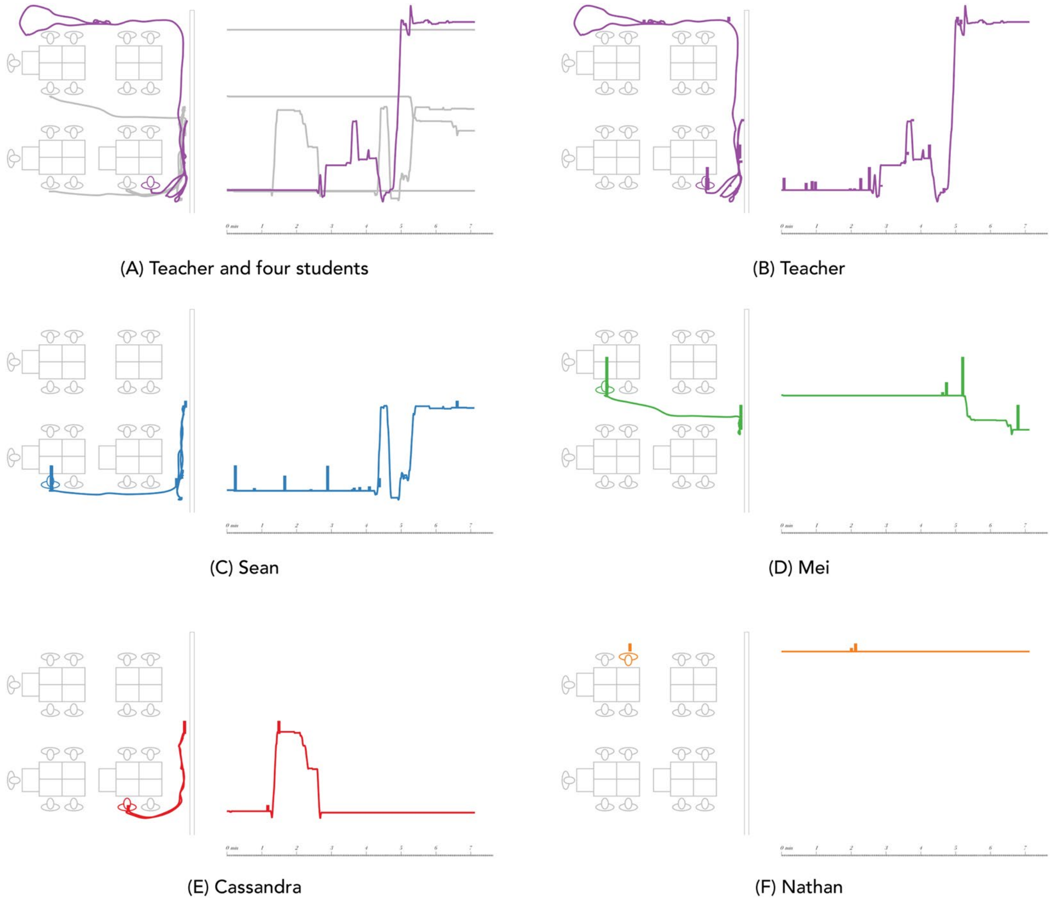

Figure 2. Teacher and student movement and conversation over space and time: (A) Teacher (purple) and four students' movement (gray); (B) Teacher movement and conversation, where rectangles indicate conversation turns and the height of each rectangle indicates the length (in words) of each turn; (C-F) Four individual students' movement and conversation. (Data used with special permission from Mathematics Teaching and Learning to Teach, University of Michigan).

focal students (in gray) who move or speak during the class discussion. Figure 2B shows the teacher's movement, but also includes each of her conversation turns, represented as purple bars along her movement path in the floor plan and space-time views. Each bar corresponds to an utterance, indicating when and where she spoke; the height of each bar indicates the length (in words) of each turn of talk. Similarly, Figures 2C-F show the movement and conversation of the four focal students — Sean, Mei, Cassandra, and Nathan. Data in each image is scaled identically, allowing comparative analysis of each participant's movement and conversation.

Figure 2 reveals patterns of interaction in the classroom, which may warrant closer analysis. During this excerpt of a whole-class discussion, we see that four students spoke. Moreover, three of these students went to the chalkboard — first Cassandra (Figure 2E, 2: 30-3:30), then Sean (Figure 2C, 4: 00-7:00), and then Mei (Figure 2D, 5: 00-7:00). Nathan, on the other hand, made two turns of talk (approximately 2:00), but remained at his seat, as indicated by a straight, unwavering line in the floor-plan view (Figure 2F). These events — where Nathan spoke up, and where the others demonstrated their thinking at the chalkboard — may indicate significant moments for their mathematical sensemaking or positioning within the classroom, which would warrant further analysis. Mondrian transcription makes these moments — and precisely where they occur in space and time — immediately visible.

Furthermore, the teacher's actions reveal other important dynamics. For instance, her talk is concentrated at the beginning of the excerpt: She made a number of lengthy utterances at the start of the conversation but said relatively little after 4:00. When Sean and Mei went to the board (approximately 4:00 and 5:00, respectively), the teacher traversed the classroom and stood off to the side. As we describe in greater detail below, this sequence of movement and talk indicates an important shift, as the teacher stepped aside to gave both physical and discursive space to students to take over the conversation.

In summary, Figure 2 highlights how Mondrian Transcription provides ways to encode talk and movement in ways that allow quick and detailed comparative analysis of individuals' movement and conversation, while also highlighting particular moments of classroom interaction of potential importance. We now turn our attention to illustrating ways to dynamically interact with these representations to visually explore movement and conversation patterns.

Using the interaction geography slicer (IGS) to explore video data

Figure 3, which is a screenshot from the IGS, extends the previous figures. We encourage readers to explore the Interaction Geography Slicer to better understand the possibilities of this tool.

Figure 3 highlights some of the capabilities of this tool, which allows users to dynamically interact with and interpret data transcribed through Mondrian Transcription, such as those in Figure 2. Figure 3 shows one of the possible views from the IGS: a teacher-centric view that shows all conversation turns during this discussion, placed along the teacher's movement path in floor plan and space-time views. Importantly, the IGS allows different ways to view movement and conversation. For example, with this data users can opt to show movement paths from students and to place conversation turns along each participant's movement path; this more precisely shows where and when each student contributed to the discussion.

Figure 3 also illustrates how users can use the IGS to hover over turns of talk to highlight, magnify, and read each utterance. In this case, we have hovered over one particular turn of talk from Sean at 2:50 to magnify and read Sean's rationale as to why he thinks six is an odd number: "you can split six fairly and you can split six not fairly..." Figure 3 also begins to show how the IGS allows users to view and interact with video and audio. Clicking the timeline in the space-time view will activate and play video from this moment of the conversation. In Figure 3, while hovering over Sean's rationale as described above, we also clicked in the space-time

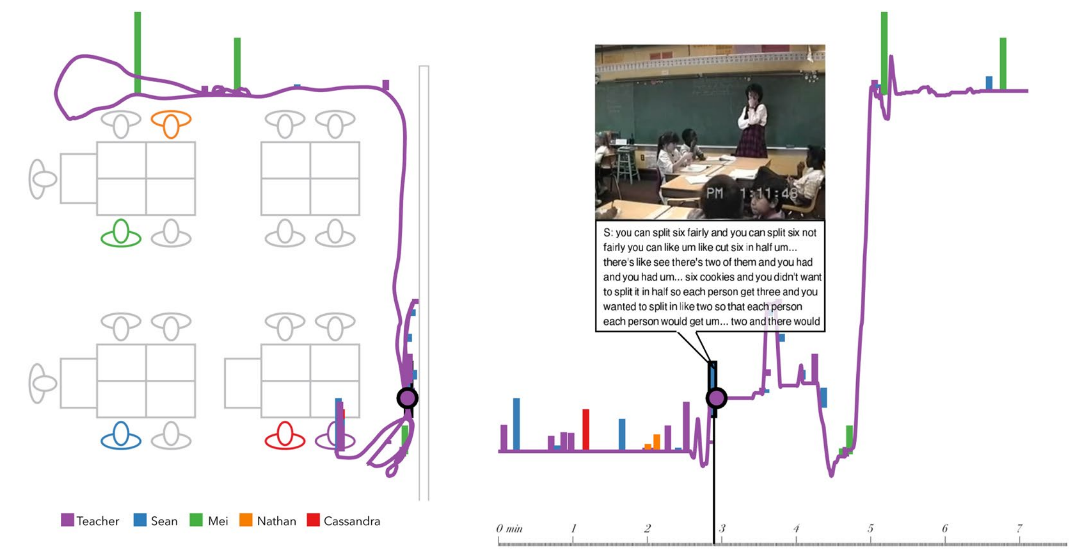

Figure 3. Screenshot from the Interaction Geography Slicer (IGS) showing the teacher's movement, with all classroom conversation placed along the teacher's movement path over space and space-time. The figure also shows how users can dynamically select and read conversation and view video with the IGS. (Data used with special permission from Mathematics Teaching and Learning to Teach, University of Michigan).

view to activate and play video at the moment when Sean made this particular utterance. Importantly, there are many ways to interact with video and audio through the IGS; we cannot show them all in a static figure. For example, users can also quickly rewind, fast forward, and select audio and video by scrubbing or hovering over the space-time view. Such interactive possibilities help to read both floor plan and space-time views together — particularly, they help to read the horizontal dimension of movement and conversation across the floor plan, which is partially lost in the space-time view without such user interaction.

In this case, the interactive possibilities of the IGS provide the ability to identify patterns of interaction and examine them more closely. At the start of this excerpt, Sean offered a conjecture that 6 could be both even and odd. The teacher invited other students to consider this idea. Cassandra voiced a dissent and went to the chalkboard to illustrate her thinking; Sean pushed back on Cassandra's point. During this exchange, the teacher remained seated, allowing Cassandra to stay at the focal point of the classroom. When Cassandra sat down, the teacher moved to the center of the chalkboard, inviting the rest of the class to join the conversation. As Sean and Mei went to the chalkboard, the teacher moved across the classroom. During Sean and Mei's debate, the teacher stood off to the side, observing the conversation rather than directing it.

In a discourse analysis of this lesson, Horn (2008) points to these as pivotal moments. As the teacher stepped aside, Horn argues, she delegated authority to the students, allowing Cassandra, Sean, and Mei to engage in a mathematical debate in front of the class. Delegating authority is a strategy central to ambitious and equitable teaching (see Dunleavy, 2015), but it is typically analyzed through discourse analysis. By juxtaposing transcripts of movement and conversation, the IGS highlights the spatial aspects of the discussion. Building on Horn's analysis, we argue that the shift in authority in this discussion is spatial, as well as discursive: As the teacher invited students to the board and moved out of the way, she provided both conversational and physical space for them to make substantive contributions to the class discussion.

In summary, interaction geography opens up new avenues for exploring classroom interaction across time and space. Established practices, like delegating authority, can take on new dimensions as we better understand how they shape (and are shaped by) movement, as well as talk. The IGS might also create opportunities for uncovering new patterns of interaction that are not readily apparent through conversation alone. Some of these patterns may be more visible at a different scale. Accordingly, we now turn to our second case to further illustrate the capabilities of the IGS when working with larger video datasets.

Case 2: Revisiting a science lesson from the TIMSS 1999 video study

Movement & conversation across a classroom lesson

Figure 4 is a screenshot from the IGS that shows the movement of a teacher, again as a purple line, over space and space-time across the 56-minute science lesson that comprises the empirical data of this case. The figure also illustrates the IGS interface that users can use to upload their own data and browse example datasets. As before, we encourage readers to explore the Interaction Geography Slicer to better understand possibilities of this tool.

The left side of Figure 4 is a floor-plan view that shows the teacher's movement around the classroom, while the right side shows a space-time view of the teacher's movement over space and time across a timeline of 56 minutes. As in previous figures, classroom conversation is shown in both views, with bars representing each turn of talk. In this case, however, the bars are colored according to the coding conventions of the original data set: Purple (T) is used for the teacher's utterances. Green, orange and blue are both used for individual students' turns; green (S) indicates that a single student is speaking; orange (SN) indicates that a new student whose identity differs from the last speaker is speaking; blue (SS) indicates that multiple students (but not the entire class) are speaking; while red (E) indicates that the entire class is speaking simultaneously. Finally, yellow (O) indicates speech from individuals who are not a part of the class (e.g., an announcement over the school's PA system).

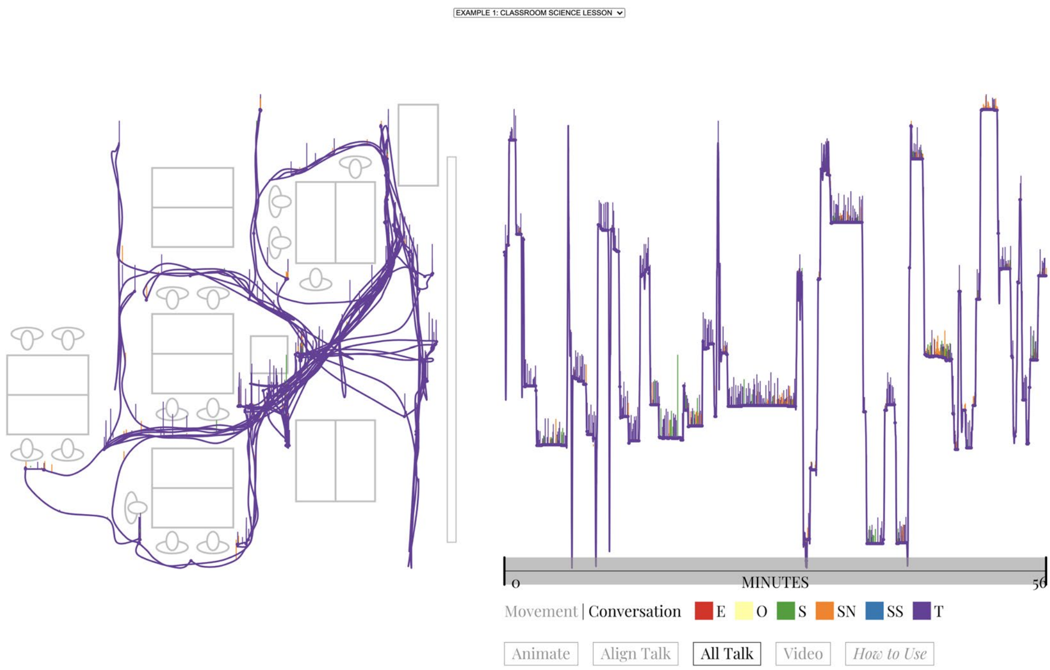

Figure 4. Screenshot from the Interaction Geography Slicer (IGS) showing a teacher's movement in purple across a 56-minute classroom science lesson from the TIMSS 1999 Video Study, with all classroom conversation placed along the teacher's movement path over space and space-time.

In comparison to the Sean Numbers case, this representation makes different phenomena visible. First, we can compare the amount of teacher talk (i.e., purple bars) and student talk across this lesson at a glance to see that the teacher made many more utterances than the students, and that the teacher's utterances were typically much longer than the students'. Such basic information is valuable to classroom researchers, but it can be difficult to see in traditional, text-based transcripts.

Second, we can compare the number and length of the teacher's and students' conversation turns across different areas of space in the classroom and different segments of time during the lesson. For example, most of the utterances in the first half of the lesson (0:00-22:00) were made by the teacher — including while she was at the projector (center of the classroom) and while she was near specific groups of students. In contrast, the second half of class (22:00-56:00) was independent seatwork; this portion of the lesson was characterized by less monological teacher talk and more conversations between students and the teacher, as shown by more orange, blue, and green bars after 22:00.

Third, we can examine the teacher's movement. For example, the floor-plan view highlights how the teacher's movement was oriented around the projector, which was located at the center of the floor plan. In other words, she repeatedly returned to this area at many different times during the lesson to address the class. Moreover, the floor-plan view highlights which tables the teacher repeatedly visited (e.g., upper right table), as well as the tables that she engaged with less often (e.g., left-most table). Simultaneously, the space-time view shows how the teacher's movement patterns shifted during different phases of the lesson: During the first half of the class, the teacher spent most of her time at or around the projector. She briefly walked to various tables, but then returned to the projector to continue addressing the class. After starting independent seatwork, however, the teacher spent little time at the projector, instead visiting each group of students in turn.

Finally, both views reveal anomalies in movement and conversation in ways that call for further analysis. For instance, there was a very long conversation turn — marked in green in the space-time view — during the seatwork portion of the class. This seemed highly unusual, since most student utterances in this class were relatively short. Closer analysis of the data revealed an error in the original transcript: multiple student turns were combined into a single turn. Representing the transcript data in this way allowed us to easily spot the error.

In summary, the figure highlights how interaction geography provides a way to integrate and represent location and conversation data across an entire classroom lesson. As a result, researchers can quickly ask and answer basic, but important, questions about classroom interaction, including: Which students or tables receive or don't receive attention during a lesson? How does the physical design of a classroom influence a teacher's efforts to visit particular table groups? What particular areas of the class do teachers repeatedly use to address a class?

Using the IGS to selectively study classroom interaction

Building on the previous figure, Figure 5 is a screenshot from the IGS that shows a selected segment from this lesson (22:00-56:00). Figure 5 shows how users can use the IGS to select a specific region of space and time for more detailed analysis. The figure shows a selection from the timeline to highlight the teacher's movement and classroom conversation during 22:00-56:00 in both floor-plan and space-time views. Likewise, the figure shows the teacher's movement during this time (in gray). On the floor-plan view, there is a circle that highlights part of the teacher's path in purple; by hovering over a segment of the teacher's path, users can illuminate the teacher's movement and classroom conversation in that area. In this case, we have hovered over a part of the floor plan near a particular student, and as a result, the space-time view reveals all of the teacher's interactions near that student during 22:00-56:00. This operation allows us to see that the teacher began working closely with this particular student at the start of the selected time (22:00); she remained at that table for nearly 7 minutes before circulating around the room to monitor other groups' work. While the teacher returned to this table multiple times throughout the rest of the lesson, all of these visits were brief. In this way, the IGS provides a way to see all of a teachers' interactions with a particular student or group during a lesson. Furthermore, the figure shows that we selected and played video from the timeline during the teacher's first interaction with that student (straight purple line in the space-time

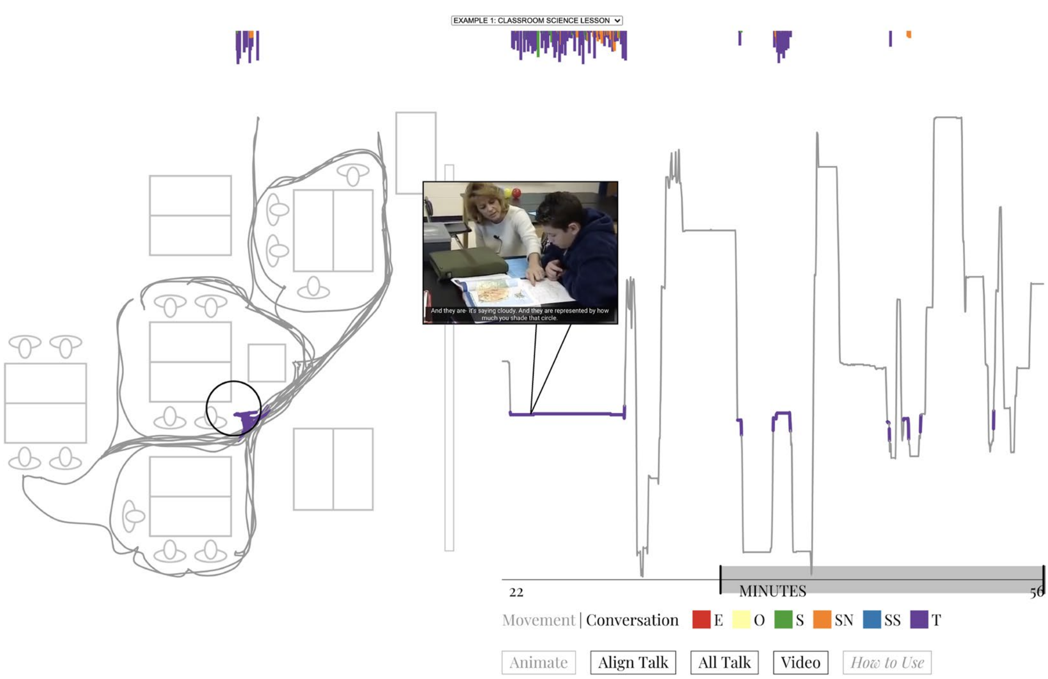

Figure 5. Screenshot from the Interaction Geography Slicer (IGS) showing dynamic selection of the teacher's movement and classroom conversation aligned horizontally above the floor plan and space-time views over a region of space and sequence of time.

view from approximately 23:00 to 30:00). Users could also use the IGS to play the sequence of the teacher's interactions with that student, which would allow us to analyze those interactions in greater detail.

Figure 5 also shows conversation from the teacher and students over the selected region of space and same segment of class (i.e., during independent seat time, 22:00-56:00). In this case however, teacher and student conversation is not attached to the teacher's movement path (as in Figure 4), but rather is aligned horizontally, above the teacher's path; this is an option that users can select in the IGS. This allows for a more precise comparison of the length of each conversation turn. Notably, this technique also shows how conversation is distributed across the horizontal dimension of the floor plan. For example, additional analysis with the IGS of this case using this type of display shows that very little conversation occured at the far right of the floor plan (the front of the classroom, near the whiteboard), while a great deal of conversation was focused on the tables toward the middle of the floor plan, near the projector. This technique also allows for a closer look at teacher-student interactions. For instance, additional analysis with the IGS shows that while the teacher was kneeling by a student (as shown in the video clip), she was primarily talking with that one student, as indicated by the green bars. Before and after that interaction, however, the teacher also engaged with other students nearby, as indicated by orange bars.

Figure 5 illustrates how the IGS supports exploratory and comparative analysis of conversation and movement during the independent seat time portion of this lesson. Notably, the figure and additional analyses with this type of display shows that the teacher's conversation turns were much longer and denser than students' conversation turns. This provides valuable information about which table groups received support from the teacher — through her proximity and the frequency and duration of her visits to different tables — as well as the conversational support she provided while visiting each table.

More generally, the figure illustrates how the IGS supports deeper analyses of teachers' instructional practices, such as their groupwork monitoring routines (Ehrenfeld & Horn, 2020). Ehrenfeld and Horn analyzed various features of teachers' interactions with groups of students, noting who initiated the interaction, how the conversation began, the focus of the conversation, how the teacher left the group, and whether the teacher spoke with the whole group or with individual students. By transcribing teachers' movement and selectively highlighting their interactions with different groups of students, the IGS facilitates analyses that build on Ehrenfeld and Horn's framework. For instance, if a teacher primarily interacts with one student in a group (as in Figure 5), viewing the sequence of interactions could add a richer understanding of the impact of her actions. If the teacher leaves the group with an open-ended question, we might note whether or not she follows up on that question in a subsequent visit. The IGS, in turn, raises new questions about how teacher monitoring patterns vary at different scales and how methods to study these patterns at different scales can be linked to describe teacher monitoring.

Moreover, the ability to hover over a portion of the floor plan and highlight all movement and conversation occurring at a point in space illustrates an analytic operation that raises new questions about spatial units of analysis (e.g., a student, table group, part of the classroom, whole classroom) and how different units can reveal meaningful patterns of movement and conversation in the IGS. In this case, a student is used as a unit of analysis to highlight when the teacher was in proximity to that student and how this changed across the lesson. While the visualizations included with this paper illustrate some of these dynamic operations to select data, there may be other operations that teachers and other researchers are best positioned to invent.

In summary, Figure 5 highlights how the IGS supports dynamic interaction with and selection of location, conversation, and audiovisual data across a complete classroom lesson. As a result, classroom researchers can quickly compare the spatial dynamics of classroom interaction during different portions of a lesson and study phenomena such as teacher monitoring routines in new ways.

Discussion

We organize our discussion across three areas. First, we summarize strengths, limitations, and next steps necessary to expand interaction geography in situative studies of classroom interaction and teaching practice. Second, we suggest ways that this approach could support teachers' video-based reflective professional practice. Finally, we offer considerations for encoding and representing classroom research data over space and time.

Strengths, limitations, and next steps

We argue that interaction geography stands to build theoretical knowledge about inherently spatial phenomena in classrooms, such as teacher monitoring routines (Ehrenfeld & Horn, 2020). Moreover, Mondrian transcription — a visual record of movement and conversation across space and time — and the ability to selectively analyze moments of interaction creates an opportunity to add a spatial perspective to other classroom phenomena, such as teacher noticing, equitable participation, and patterns of inclusion and exclusion (see Shah & Coles, 2020).

In future iterations of this work, we anticipate expanding the set of classroom research applications and scaling Mondrian transcription and the IGS as freely available open-source projects. For example, we hope to develop instructional materials that demonstrate the process of Mondrian transcription so that others can create their own Mondrian transcripts. We also hope to customize the views and interaction techniques within the IGS so that teachers and researchers can pose and explore their own questions about their instructional contexts. Likewise, we hope to address particular limitations with technologies and conventions illustrated in this paper. These limitations include developing ways to input a variety of forms of manual or automated positioning data into the IGS and challenges associated with reading space-time views. While some of these limitations will be addressed in future work, others highlight the limits of interaction geography as an exploratory visualization approach.

Supporting teachers' Video-Based reflective professional practice

Video is an established and powerful medium used by teacher education researchers to support teacher's reflective professional practice (Borko et al., 2008; Calandra & Rich, 2014; Louie, 2018; Sherin & van Es, 2009). Notably, video analysis allows teachers to gain a richer view of classroom interaction, including a deeper understanding of the dilemmas teachers face and the choices they make during instruction, as well as the subsequent effects on student learning. However, researchers acknowledge that this work is challenging because it is time-consuming for teachers to watch and make selections from an entire classroom video (see Derry et al., 2010).

Interaction geography offers particular ways to address these challenges. With further development and collaboration with teachers, we anticipate that tools like the IGS could be adapted to support teachers' reflective professional practice. Likewise, interaction geography offers one approach that could allow teachers to identify and reflect on spatial aspects of their teaching practice, without sacrificing an attention to conversation and other phenomena made visible through video data.

Encoding & representing classroom research data over space and time

Our analysis of both cases in this paper raises new and important questions about how classroom research data is encoded and represented over space and time, particularly because existing transcription methods, coding schemes, and emerging learning analytics systems continue to encode and represent classroom data over time, but not space.

For example, to support the work in this paper, we used Mondrian Transcription to transcribe video collected nearly 30 years ago. While transcripts of conversation were available in both cases, we manually transcribed individuals' movement. More modern technologies, such as computer vision and positioning sensors, could automate the transcription process. But just as voice recognition software creates imperfect transcripts of conversation, automated transcripts of movement may also include significant errors. This raises important questions about whether (or when) automated processes should be used to generate transcripts of movement, for instance: Does manually transcribing movement offer greater detail or insight? Can automated methods produce transcripts that are sufficiently accurate? How can manual and automated transcription techniques be integrated to support teachers' reflective professional practice?

Furthermore, while the work in this paper presents one approach to encoding and representing classroom data over space and time, it also suggests that there may be other approaches with different strengths and weaknesses for studying classroom interaction and teaching practice. This raises additional questions about the coding schemes and units of analysis that might inform future qualitative studies of teachers' and students' mobility in classrooms. For instance: What do different spatial units of analysis offer studies of classroom interaction? What patterns of movement and conversation arise in classrooms? In the future, a taxonomy or typology of those patterns could inform teachers' use of space or even the physical design of classrooms.

Conclusion

In summary, this paper illustrates a new video-based methodological approach that can better account for both the spatial and temporal dimensions of classroom interaction. We conclude by underscoring the importance of advancing discussions about data ethics when using visualizations of classroom interactions. Collecting data on teacher and student movement should raise concerns about privacy, the growth in surveillance in schools, and the need for policies to guide appropriate use of increasingly automated data collection in public and private spaces. Approaches such as interaction geography that use dynamic, interactive visualizations raise a host of new ethical questions for education technology researchers and designers including: How are insights from these data generated and interpreted by different audiences? Who has access to the data, and in what forms or for what purposes? How can people customize tools such as the IGS, for example, to set their own privacy preferences (see Martinez-Maldonado, 2019)? In line with prior work that has used interaction geography as part of an effort to teach data ethics and work closely with practitioners (Shapiro et al., 2020), it is critical that interaction geography and similar methods be used in close collaboration with practitioners so that it benefits students and teachers, while also recognizing that there will be settings where such approaches are not appropriate.

Acknowledgments

The authors wish to thank Deborah Loewenberg Ball, Kara Suzuka, and Mathematics Teaching and Learning to Teach, University of Michigan for special permission to revisit the case of Sean Numbers as described in this paper. The authors also wish to thank members of the Project SIGMa team, including Ilana Seidel Horn, Patricia Buenrostro, Grace A. Chen, Nadav Ehrenfeld, Lara Jasien, Samantha A. Marshall, Elizabeth Metts, Katherine Schneeberger McGugan, Jessica Moses, Maria Aguilera, and Kathleen Janik, as well as Amy Vo and the anonymous reviewers for their comments on earlier versions of this paper An early version of ideas extended in this paper was published in the Proceedings of the 14th International Conference of the Learning Sciences (see: Shapiro, Garner, Chae & Natriello, 2020).

Notes on contributors

Ben Rydal Shapiro, Ph.D., is an Assistant Professor of Learning Technologies in the Department of Learning Sciences at Georgia State University. Previously, he was a postdoctoral fellow in the School of Interactive Computing at Georgia Institute of Technology and completed his Ph.D. in Learning Sciences at Vanderbilt University. His research and design integrates approaches from the learning sciences, information visualization, and computer

science to study how people learn in relation to the physical environment and to develop new types of learning environments and experiences that support data science education.

Brette Garner, Ph.D., is an Assistant Professor of Mathematics Education in the Department of Teaching and Learning Sciences at the University of Denver's Morgridge College of Education. Previously, she completed her Ph.D. at Vanderbilt University. Her research and scholarship focus on secondary mathematics teachers' learning through design-based research interventions.

ORCID

Ben Rydal Shapiro http://orcid.org/0000-0001-8070-0952
Brette Garner http://orcid.org/0000-0001-9626-8826

References

Ball, D. L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. *The Elementary School Journal*, *93*(4), 373–397. https://doi.org/10.1086/461730
Ball, D. L., Ben-Peretz, M., & Cohen, R. B. (2014). Records of practice and the development of collective professional knowledge. *British Journal of Educational Studies*, *62*(3), 317–335. https://doi.org/10.1080/00071005.2014.959466
Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*, *24*(2), 417–436. https://doi.org/10.1016/j.tate.2006.11.012
Calandra, B., & Rich, P.J. (Eds.). (2014). *Digital video for teacher education: Research and practice* (1st ed.). Routledge.
Cazden, C. (2001). *Classroom discourse: The language of teaching and learning* (2nd ed.). Heinemann.
Cleveland, B. (2009). Equitable pedagogical spaces: teaching and learning environments that support personalisation of the learning experience. *Critical & Creative Thinking*, *17*(2), 59–76.
Cohen, D. (2011). *Teaching and its predicaments*. Harvard University Press.
Cohen, E. G., & Lotan, R. A. (2014). *Designing groupwork: Strategies for the heterogeneous classroom* (3rd ed.). Teachers College Press.
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. https://doi.org/10.1080/10508400903452884
Dunleavy, T. K. (2015). Delegating mathematical authority as a means to strive toward equity. *Journal of Urban Mathematics Education*, *8*(1), 62–82.
Ehrenfeld, N., & Horn, I. S. (2020). Initiation-entry-focus-exit and participation: A framework for understanding teacher groupwork monitoring routines. *Educational Studies in Mathematics*, *103*(3), 251–272. https://doi.org/10.1007/s10649-020-09939-2
Erickson, F., Dorn, S., & Artiles, A. (2017). *Learning how to look and listen: Building capacity for video based social & educational research*. Spencer Foundation. https://www.learninghowtolookandlisten.com/
Greeno, J. (1998). Where is teaching?. *Issues in Education*, *4*(1), 111–119. https://doi.org/10.1016/S1080-9724(99)80079-2
Hagerstrand, T. (1970). What about people in regional science?. *Papers in Regional Science*, *24*(1), 6–21.
Herbel-Eisenmann, B. A., & Breyfogle, M. L. (2005). Questioning our patterns of questioning. *Mathematics Teaching in the Middle School*, *10*(9), 484–489. https://doi.org/10.5951/MTMS.10.9.0484
Horn, I. S. (2008). Chapter 3: Accountable argumentation as a participation structure to support learning through disagreement. *Journal for Research in Mathematics Education. Monograph*, *14*, 97–126.
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
Kendon, A. (1990). *Conducting interaction: Patterns of behavior in focused encounters*. Cambridge University Press.
Lampert, M., & Cobb, P. (2003). Communication and Language. In J. Kilpatrick, W.G. Martin, & Deborah Schifter (Eds.), *A research companion to principles and standards for school mathematics* (pp. 237–249). National Council of Teachers of Mathematics.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.
Leander, K. (2002). Locating Latanya: The situated production of identity artifacts in classroom interaction. *Research in the Teaching of English*, *37*(2), 198–250.
Lim, F. V., O'Halloran, K. L., & Podlasov, A. (2012). Spatial pedagogy: mapping meanings in the use of classroom space. *Cambridge Journal of Education*, *42*(2), 235–251. https://doi.org/10.1080/0305764X.2012.676629

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics*, *97*(1), 55–69. https://doi.org/10.1007/s10649-017-9775-2

Ma, J., & Singer-Gabella, M. (2011). Learning to teach in the figured world of reform mathematics: Negotiating new models of identity. *Journal of Teacher Education*, *62*(1), 8–22. https://doi.org/10.1177/0022487110378851

Martinez-Maldonado, R. (2019). I spent more time with that team: Making the spatial pedagogy visible using positioning sensors. *Proceedings of the 9th Learning Analytics and Knowledge Conference,* USA. (pp. 21–25).

Martinez-Maldonado, R., Schulte, J., Echeverria, V., Gopalan, Y., & Shum, S. B. (2020). Where is the teacher Digital Analytics for classroom proxemics. *Journal of Computer Assisted Learning*, *36*(5), 741–762. https://doi.org/10.1111/jcal.12444

Mathematics Teaching and Learning to Teach (MTLT), University of Michigan (2010). *Sean Numbers-Ofala*. http://hdl.handle.net/2027.42/65013

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Harvard University Press.

Monahan, T. (2005). *Globalization, technological change, and public education*. Routledge.

O'Connor, M. C., & Michaels, S. (1993). Aligning academic task and participation status through revoicing: Analysis of a classroom discourse strategy. *Anthropology & Education Quarterly*, *24*(4), 318–335. https://doi.org/10.1525/aeq.1993.24.4.04x0063k

Shah, N., & Coles, J. (2020). Preparing teachers to notice race in classrooms: Contextualizing the competencies of preservice teachers with antiracist inclinations. *Journal of Teacher Education*, *71*(5), 584–599. https://doi.org/10.1177/0022487119900204

Shapiro, B. R., Garner, B., & Chae, H. S., Natriello, G. (2020). Classroom interaction geography: A case study. In *Proceedings of the 14th International Conference of the Learning Sciences (ICLS). International Society of the Learning Sciences* (Vol. 4, pp. 1823–1830).

Shapiro, B. R., Hall, R., & Owens, D. (2017). Developing & using interaction geography in a museum. *International Journal of Computer-Supported Collaborative Learning*, *12*(4), 377–399. https://doi.org/10.1007/s11412-017-9264-8

Shapiro, B. R., Meng, A., O'Donnell, C., Lou, C., Zhao, E., Dankwa., B., & Hostetler, A. (2020). Re-shape: A method to teach data ethics for data science education. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM, Honolulu, HI, USA, Paper 124. https://doi.org/10.1145/3313831.3376251

Sherin, M. G., & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education*, *60*(1), 20–37. https://doi.org/10.1177/0022487108328155

Sherin, M. G., Jacobs, V., & Philipp, R. (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. Routledge.

Stake, R. E. (1995). *The art of case study research*. SAGE.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, *33*(2), 455–488. https://doi.org/10.3102/00028312033002455

Stigler, J. W., & Hiebert, J. (2009). Closing the teaching gap. *Phi Delta Kappan*, *91*(3), 32–39. https://doi.org/10.1177/003172170909100307

Third International Mathematics and Science Study (TIMSS) Video Study. (1999). *TIMSS Video*. http://www.timssvideo.com

van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education*, *10*, 571–596.

Wilhelm, A. G. (2014). Mathematics teachers' enactment of cognitively demanding tasks: Investigating links to teachers' knowledge and conceptions. *Journal for Research in Mathematics Education*, *45*(5), 636–674. https://doi.org/10.5951/jresematheduc.45.5.0636

Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education*, *27*(4), 458–477. https://doi.org/10.2307/749877

Yin, R. (2009). *Case study research. Design and methods* (4th ed.). Sage.