Visualizing Spatial Pedagogies in a Maker-Based Classroom: An Interaction Geography Perspective

ACCEPTANCE

This dissertation, VISUALIZING SPATIAL PEDAGOGIES IN A MAKER-BASED CLASSROOM: AN INTERACTION GEOGRAPHY PERSPECTIVE, by SIERRA D. GILLIAM, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree, Doctor of Philosophy, in the College of Education & Human Development, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairperson, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty.

____
Benjamin Shapiro, Ph.D.
Committee Chair

____
Jonathan Cohen, Ph.D.
Committee Member

____
Ilana Horn, Ph.D.
Committee Member

____
Lauren Margulieux, Ph.D.
Committee Member

____
Date

____
Brendan Calandra, Ph.D.
Chairperson, Department of Learning Sciences

____
Paul Alberto, Ph.D.
Dean, College of Education & Human Development

AUTHOR'S STATEMENT

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SIERRA D GILLIAM

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Sierra D. Gilliam
Learning Sciences
College of Education & Human Development
Georgia State University

The director of this dissertation is:

Benjamin Shapiro, Ph.D.
Department of Learning Sciences
College of Education & Human Development
Georgia State University
Atlanta, GA 30303

CURRICULUM VITAE

Sierra D. Gilliam

ADDRESS: 6724 Morgantown
St. Raleigh,
NC 27616

EDUCATION:

Ph.D.	2025	Georgia State University Atlanta, Georgia Instructional Technology
M.S.	2018	North Carolina Central University Durham, North Carolina Earth Science
B.S.	2013	North Carolina Central University Durham, North Carolina Environmental Science

PROFESSIONAL EXPERIENCE:

2021-present	Executive Assistant Morehouse College Atlanta, Georgia
2021-2022	Apple Care Home Advisor Apple INC Cupertino, California
2020-2021	Career and Technical Education (C Innovator, Guilford County Public Greensboro, NC
2016-2018	Geographic Information System (GIS) Research Assistant, NASA Center for Aerospace Device Research and Education Durham, North Carolina

CURRICULUM VITAE

PRESENTATIONS:

Gilliam, S.D., Williams, A., Shapiro, B.R., Garner, B., Metts, E., & Jasien, L. (2023, March). *Incorporating Space and Movement into Teachers' Video-Based Reflective Practice: An Interaction Geography Perspective*. Poster presented at American Educational Research Association annual meeting. Chicago, IL

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Shapiro, B. R., Gilliam, S.D., Metts, L., Garner, B., Yong, D., & Horn, L. (2022, April). *Visually exploring teachers' use of space in the classroom*. Presentation for Mathematics for America, Los Angeles

Gilliam, S.D. (2021, October). *Technology ethics in computer science*. Presentation for the Mozilla Foundation Responsible Computer Science Challenge, Virtual

Gilliam, S.D. (2018, January) *Spatial query of GIS data to support health disparity research*. NASA Center for Aerospace Device Research and Education Poster presented at Graduate College of Health and Sciences Annual Research Symposium, North Carolina Central University, Durham, NC.

Gilliam, S.D. (2018, April) *Georectification of North Carolina Central University football field*. Presented at Graduate College of Health and Sciences, North Carolina Central University, NCCU Annual Research Symposium, North Carolina Central University, Durham, NC.

PUBLICATIONS:

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by

SIERRA D. GILLIAM

Under the Direction of Benjamin Shapiro, Ph.D.

ABSTRACT

Maker-based classrooms are unique educational settings that offer rich and diverse opportunities for student learning. Within these contexts, the design of physical space and movement are central to teaching and learning. However, little work has explored the role of teachers' physical movement and use of space in maker-based classroom environments. In parallel, a growing body of work in teacher education is beginning to highlight the importance of teachers' movement and use of space to responsive teaching. My dissertation bridges these two areas of research by using a case study approach and a geospatial visualization method called *interaction geography* to investigate teachers' spatial pedagogies in a maker-based classroom. Specifically, I visually explore how three instructors in a university-level maker-education based course incorporated diverse spatial pedagogies across a semester. Findings advance concepts and methods to understand teaching as a situative and spatial practice in maker-based learning environments and have implications for teachers, teacher educators, architects, administrators, and researchers interested in the design and use of physical classroom spaces.

INDEX WORDS: Interaction Geography, Teacher Education, Spatial Pedagogy, Maker Education, Teacher Movement, Case Study, Qualitative Methods

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DEDICATION

This manuscript is in dedication to Rakeem Vick II, Moses Mulligan, Eli Gilliam, Dorothy R. Gilliam, Skylar D. Gilliam, Andrew Gilliam, and others who did not live to see this day but to whom I owe the honor and privilege of being who I am today Ada Mae Gilliam, Dorothy Jean Speight, Edward Earl Gilliam, Tyrone Speight, Janie Gilliam, Clara Speight, Mary Ellen and a host of other family members and friends. Furthermore, I want to dedicate this work to my childhood church home Christian Praise Church of SE Washington, DC. Pastor Jessie Andrus as well as those who encouraged me along the way. Thank you and to God be the glory!

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1. BACKGROUND

Overview of Study

Maker-based classrooms are unique educational settings that combine elements of traditional classrooms with the creative focus of makerspaces. Often described as dynamic hubs for learning and innovation, these classrooms offer rich opportunities for student learning through hands-on exploration and design. Prior research has focused on several key dimensions of maker-based classrooms, including their capacity to afford novel interest-driven engagements, collaborative knowledge building, and learning experiences through creative activities and pedagogies that engage learners with a range of digital, hands-on tools and artifacts in a classroom environment (Blikstein 2013; Cohen et al., 2017; Halverson and Sheridan, 2014; Kajamaa & Kumpulainen, 2021).

Crucially, the design of physical space and movement are central to teaching and learning within maker-based classrooms. Unlike traditional classroom environments which often feature fixed furniture, clearly demarcated instructional zones, and limited opportunities for open-ended exploration, maker-based classrooms demand spatial flexibility. These environments are characterized by hands-on, collaborative, and iterative learning activities that involve diverse tools, materials, and group configurations. As Sheridan et al. (2014) emphasize, maker-based classrooms foster learner-centered pedagogies grounded in exploration, tinkering, and experimentation, all of which require spatial activity and arrangements that are adaptable and responsive to evolving instructional needs. However, despite the growing body of research on makerspaces and maker-based classrooms, little attention has been given to the role of teachers' physical movement and use of space in these settings.

In parallel, a growing body of work in teacher education is beginning to highlight the importance of teachers' movement and use of space in teaching as part of broader calls for a spatial turn in teacher education (Blaisdell, 2020; Ellis & Goodyear, 2018; Larnell & Bullock, 2018; Marin et al., 2020; Weiland & Poling, 2022). For example, Lim et al., (2012) propose the notion of *spatial pedagogy* to underscore the importance of how teachers use classroom space as a semiotic resource to support student learning (also see Martinez-Maldonado et al., 2020). Likewise, Ehrenfeld & Horn

(2020) highlight the diverse ways teachers use space and movement to support *groupwork.* Others have begun to highlight that where and how teachers position themselves and move through classrooms affects *how* instruction is framed and perceived (Rubel & Nicol, 2022), *what* kinds of disciplinary engagement are accessible to multilingual learners (Yeh et al. 2025), and *how* emotional and empathetic dynamics influence students' sense of belonging (de Freitas et al., 2022, Jaber et al., 2024; Silvis et al, 2025).

My dissertation bridges these distinct bodies of work to advance research concerning the physical design and use of maker-based classrooms. Through a case study approach that incorporates methods of *interaction geography* (Shapiro et al., 2024; 2025), I visually explore the diverse spatial pedagogies used by three instructors across a semester in a university-level maker-education based course. In doing so, I integrate and extend existing research to characterize the complex ways teachers use space and movement as part of their pedagogical practice within the context of a university-level maker-education based course.

Significance of the Study

Findings from this study have several implications for researchers, practitioners, and administrators involved in the design, operation, or study of formal and informal maker-based classroom settings as well as traditional classroom settings that foster hands-on, collaborative learning activities

First, this study extends prior research by advancing both conceptual and methodological approaches for analyzing teacher movement and spatial patterns in classroom settings. While earlier work has largely focused on the actions of a single teacher within the confines of a single lesson, this study examines how spatial practices evolve across multiple lessons and among teaching teams over the course of an entire semester. This broader temporal and collaborative lens offers valuable insights into how teachers in maker-based classrooms use movement and space to equitably distribute attention, coordinate instructional roles, organize classroom activity, and foster sustained student engagement.

Second, this study advances methods of interaction geography, which have been adopted and expanded in fields ranging from early childhood education (Berson et al., 2023), teacher education (Horn et al., 2024; Metts et al., 2024), smart classrooms, (Wu et al., 2023), museum studies (Shapiro et al., 2017), and interior design (e.g., Vo & Huesemann-Odom, 2022). Particularly, this study will explore how interaction geography is uniquely suited to characterize multiple teachers' complex movement and spatial patterns in maker-based classrooms, further identifying strengths and limitations of this approach to integrate transcripts of movement and conversation alongside video and characterize spatial and movement patterns in classrooms.

Third, the concepts and methods developed in this study have implications not only for teachers and teacher educators, but also for architects, administrators, and researchers concerned with the physical design of classrooms. Designers can leverage the concepts, methods, and insights gained from this research to design flexible and adaptable educational spaces that accommodate the dynamic nature of maker-based learning and teaching activities. By comprehensively understanding the interactions between teachers and students within these environments, designers can develop layouts that facilitate movement and collaboration, thereby further supporting diverse and responsive pedagogical strategies and enhancing opportunities for learning. Likewise, administrators can leverage these findings to develop more robust policies and guidelines concerning the physical design of classroom settings, including maker-based classrooms.

Assumptions and Limitations

This qualitative case study also has several important limitations. First, it focuses on one very particular kind of maker-based classroom. While I hope the concepts and methods developed through this work will have utility for a variety of classroom settings, future studies will be needed to further generalize this work to other kinds of maker-based classrooms and classroom environments.

Second, interaction geography is only one kind of method to explore space and movement. It is important to recognize that there are other methods that would yield qualitatively different insights about teacher's use of movement and space.

Third, understanding teachers' movement and spatial patterns alone does not fully capture the extent of activities, teaching, and learning that occur in maker-based classrooms. For instance, my emphasis on teachers' actions does not include analyses of students' talk or reflections, which could reveal how teacher movements influence student engagement, collaboration, and learning outcomes.

Finally, my analysis relies on video records collected in one maker-based classroom context that focus on capturing teachers' movement and spatial patterns while backgrounding other elements such as the details of students' group conversations. Put simply, these records are limited and support certain kinds of theoretical development while backgrounding others.

2. REVIEW OF THE LITERATURE

This study draws from and integrates three bodies of literature. First, it is informed by situative views of teaching that emphasize how teaching and learning are an interactional accomplishment, constituted in relation to learners and communities (Ball, 1993; Cazden, 2001; Horn & Garner, 2022; Lampert & Cobb, 2003; Lave, 1996). This scholarship stresses the importance of interactions between teachers, learners, and broader communities that shape teaching practice and opportunities for student learning. My study draws from a situative view of teaching and learning to focus on how teaching occurs through ongoing interactions between teachers, physical space, and larger communities of learners. Visualizing movement patterns and characterizing teachers' use of space aligns with a situative view that teaching is not merely about delivering content but about actively engaging students within a dynamic, interactive setting that reflects the community's values and learning goals.

Second, my research efforts are deeply rooted in the context of maker education, a field that emphasizes hands-on, student centered learning in creative, collaborative environments (Cohen et al., 2017; Martin, 2015; Halverson & Sheridan, 2014; Clapp et al., 2017; Papert & Harel, 1991). Specifically, my study draws from and extends this body of work to advance an understanding of how space and movement are important dimensions of teaching and learning in maker-based classroom settings. Illustrating how teachers use movement and space within maker-based classrooms provides insights into how they use space to promote creativity, foster student engagement, and support collaborative work. By examining how teachers navigate and interact within these unique learning environments, researchers can better understand how space and movement contribute to creating a flexible, responsive atmosphere that supports student-driven exploration crucial to maker-based education.

Third, my study is informed by a growing body of work that studies teachers' movement and use of space in classrooms (Lim et al., 2012; Martinez-Maldonado et al., 2021; Ehrenfeld & Horn, 2020; An et al., 2018; Yeh et al., 2025; Weiland & Poling; Tissenbaum et al., 2022; Liljedahl, 2016). This literature explores not only the physical movement of teachers around the classroom but also considers how their spatial choices influence student engagement, classroom management, and the overall learning environment. By observing and analyzing teachers' spatial choices, researchers can gain insights into how specific movement patterns such as circulating among groups, positioning near certain students, or utilizing different zones in the classroom can foster a more dynamic and inclusive learning environment.

In the following, I unpack each of these bodies of literature, highlighting how my study draws from and contributes to each.

Teaching as a Situative Practice

As stated previously, situative views of teaching emphasize how teaching and learning are an interactional accomplishment, constituted in relation to learners and communities (Ball, 1993; Cazden, 2001; Horn & Garner, 2022; Lampert & Cobb, 2003; Lave, 1996). From such a perspective, learning occurs through participation and interactions with other students, teachers, and materials. Students learn through their involvement in meaningful activities, discussions, and collaborations within the learning environment. For example, such situative perspectives on teaching lead to understanding learning as a fundamentally participatory and social process (Staples, 2007). Likewise, an important finding from this work is the extent to which instruction is deeply shaped by students, teachers, and cultures (Lave, 1996).

Participation Metaphors

Situative perspectives on teaching draw from several theoretical ideas and concepts. In the following, I review a few particularly important ones including how situative perspectives draw from participation metaphors on learning (Sfard, 1998), communities of practice (Lave & Wenger, 1991) and connections to sociocultural theory (Vygotsky). For example, Sfard's (1998) foundational work characterized differences between what she described as acquisition and participation metaphors. Acquisition metaphors focus on how individual learners acquire content and are foundational to cognitive perspectives on learning. In contrast, participation metaphors identify learning as a social process distributed across tools, other people, and activities and are thus central to situative perspectives on teaching. For example, O'Connor & Michaels (1993) suggest how social participation structures the roles and stances taken on by students as they engage with the teacher and other students highlighting one-way situative perspectives embody participation metaphors. This exploration aligns closely with the core emphasis on situative perspectives on teaching and learning, emphasizing the participatory nature of education. Students actively engage with their teachers and classmates as they contribute to knowledge through dialogue, collaboration and shared experiences.

Notably, Sfard (1998) argues that relying solely on one metaphor can lead to a limited understanding of learning or teaching. Likewise, she suggests that educators should incorporate the participation metaphor to emphasize the importance of engaging learners in authentic contexts and promoting active involvement in communities of practice (COP). For instance, in a maker-based classroom, multiple teachers working together exemplify this approach by embodying a community of practice. Their unconscious coordinated movement across the space helps foster a participatory culture where students are encouraged to engage in collective problem-solving, collaborate with peers, and interact with materials in ways that reinforce learning as a social, relational process. Learners come together with a shared interest, focus or expertise that binds the community members together providing a common ground for members to explore, learn and develop their understandings.

Researchers have extended the notion of COP in several ways important to situative perspectives on teaching. For example, the notion of communities of learners (Rogoff, 2009) underscores how classrooms are organized as communities through teaching. Likewise, Brown & Duguid's (1991) research also extends the concept of communities of practice to understand the role of culture, context, and social interactions in learning. COP complements this study setting because of its significant role in fostering learning in makerspaces through collaboration.

COP facilitates the exchange of knowledge, inspires creativity, and provides a platform for skill development that accelerates individual and collective learning. As part of their work on COP, Lave & Wenger (1991) also discovered that newcomers (learners) engage in peripheral activities on the fringes of a community of practice before gradually becoming full participants in the core activities.

Sociocultural Theory

Lev Vygotsky's foundational work established sociocultural theory and ideas focusing on how knowledge is developed through an interactional process of two or more individuals. Vygotsky highlights the importance of social interactions, collaboration, and shared experiences in the development of knowledge and cognitive skills. Interpreting this as it relates to my research implies that learners can construct knowledge when actively participating in the making and publicly sharing of a physical object (Papert, 1991) as well as how teaching is an interactional accomplishment. This perspective encourages a deeper view of how activities promote human development and learning opportunities.

Social engagement is a dominant condition surrounding aspects of the maker culture due to sharing . The maker movement advocates for social and technical practices. This includes culture, embodiment, and design, all adopting learning using sociocultural perspectives. Dewey (1916) highlights that thinking and feeling related to association with others is a social mode of behavior.

Learners become situated with ideas and creations by acknowledging innovations that have been done before or are happening among the people around them. Vygotsky's view on sociocultural learning was to understand how human social and mental activities are organized through culturally constructed artifacts (Bull et al.,2022). This literature aligns well with understanding how teachers' movement patterns might evolve across different lessons and throughout a semester in a maker-based classroom environment, where sociocultural dynamics play a central role.

As Vygotsky notes, knowledge and cognitive skills are co-constructed through meaningful interactions. Similarly, in a maker-based classroom setting, the teachers' evolving movement patterns allow them to create and adjust learning opportunities that match the developmental stages of students' projects and their collaborative needs. This aligns with Papert's (1991) ideas, where learning is fostered through the process of making and publicly sharing physical objects.

In summary, situative studies of teaching focus on how teaching and learning are interactional accomplishments. Situative perspectives advocate for authentic learning tasks that mirror real-world situations, fostering a deep and meaningful engagement with the subject matter. This perspective highlights the significance of social interaction in the learning process. Learning is viewed as a collaborative effort that promotes social interactions that highlights meaningful engagement among teachers, students and the environment. However, one significant gap is that situative perspectives have rarely focused on physical space and teachers' movement as crucial to classroom interaction. This study is grounded in situated views of teaching and extends such views to further consider how space and movement are important components of teaching and learning.

Maker Education

Maker education centers on the principle of hands-on, project-based activities which stimulates deeper learning and cognitive engagement. This approach is grounded in constructivist theories (Ackermann, 2001; Papert, 1991), emphasizing how students learn by doing and constructing knowledge through interaction with materials and tools. Maker-centered education frequently unfolds in environments like classrooms, afterschool programs, community centers, and libraries. These environments are often categorized as formal or informal learning hubs where students engage in activities from coding to crafting, making this approach highly dependent on the environment and physical space where learning happens. Maker-based education is a learning approach that fosters opportunities for students to explore, learn and share through the art of creation from diverse backgrounds and interests.

For example, Cohen et al. (2017) suggests digital technologies can be leveraged to produce and share physical artifacts with a much broader community. Blending digital and physical technologies together can help explore new ideas, learn technical skills, and create new products (Martin, 2015). It's important to understand that maker education not only can leverage opportunities to enhance practices of engineering and STEM but also the humanities and social sciences. It is a flexible learning approach that can be applied in many disciplines as long as there is an iterative design process fostered in its production of new artifacts.

In a typical maker-based educational environment, it is important to highlight how the teacher movement plays a pivotal role in fostering student engagement, exploration, and autonomy in learning. Observing movement from a spatial approach enables dynamic observations of ways teachers engage with students individually or in small groups, prompting critical thinking and encouraging creative problem-solving through targeted questions and constructive challenges. Maker-based education also encourages development of practical skills that can be applied to real world contexts. In the following, I will review the notion of constructionist perspectives on teaching and maker-based approaches used in teacher education that inform my work.

Constructionism

Constructionist perspective on learning is particularly central to maker education and acknowledges that learners can construct knowledge when they actively participate in the making and publicly sharing of a physical object (Papert & Harel, 1991). The idea of making encourages students to approach design practices personally to explore new ideas. Learners create products they can share with a greater audience. For example, Martin (2015) suggests that physical creations can create a context for social engagement around a shared venture. This perspective connects to maker-centered learning by acknowledging that making is building through creativity that's shared among other people. Papert's perspective on constructionism focuses on the significance of making in learning (Ackerman, 2001). Papert's theory is rooted in Piaget's constructivist approach to learning. Seymour Papert was a student of Piaget and the co-founder of the MIT Artificial Intelligence Lab (Bull et al., 2022). Both views consider the construction of knowledge and study how learners develop and understand over a specific period of time (Ackerman,2001).

This perspective emphasizes on building knowledge structures to engage with experiences responsible for encouraging a personal construction of an artifact (Papert & Harel, 1991). Martin's (2015) research concepts of the maker mindset consider the value of constructionist perspectives through the lens of learning through play, promoting engagement, inclusion, and motivation through students' hands-on activities in maker learning. Martin (2015) suggests no set definition of what making is exactly, however it is part of what has been identified as "design-make-play learning methodologies" (Halverson & Sheridan, 2014, pp. 2) argues that research on making in education using a constructionist learning approach can successfully leverage making into formal learning environments.

This perspective encourages a deeper view of how materials, software, or other educational resources could prompt human development and learning opportunities. Cohen et al. (2017) suggest researchers should focus on two pillars of constructionism, making and sharing, as they relate to a newly developed framework called makification. When we advocate for formal learning frameworks like makification to be rooted in teachers' pedagogy, we connect the maker mindset with existing learning goals and objectives by promoting more hands-on learning experiences for students.

Maker-based Approaches in Teacher Education

Maker-based approaches in teacher education suggest that spatial awareness and fluid movement patterns are integral to creating an atmosphere of collaboration, allowing educators to become facilitators of an interactive, community-centered classroom experience (Schad & Jones, 2019; Caratachea, et al. 2023; Martin & Dixon, 2016). Research on integrating maker principles into K-12 classrooms is developing (Schad & Jones, 2019), with similar early-stage research focused on incorporating these principles into teacher education and professional development (Caratachea et al., 2023; Schad & Jones, 2019). Studies indicate that maker-based teacher education can enhance pre-service and in-service educators' approaches to fostering active, collaborative, and student-centered learning environments (Cohen et al., 2020; Jin, 2021). Expanding on this research provides valuable insights into how teacher movement within the classroom can be viewed through a spatial lens, particularly as it relates to fostering a maker-centered, collaborative environment. In classrooms that incorporate maker principles, the physical space and teacher's mobility within it play essential roles in facilitating active learning and engagement.

In conclusion, maker education is an approach that highlights creation and exploration fostering learning through design and creativity. It promotes critical thinking, creativity, problem-solving, and multimodal skills. Representation of various modes of communication and learning is expressed often in maker-based classrooms. My study will explore dimensions of teaching and learning in a maker-based classroom that have received little attention: Namely, how teachers use their movement to support student learning. Such a focus further extends work in maker education with situative studies of teaching in more traditional classrooms, while linking such ideas with recent work illustrating the importance of space and movement in classroom teaching reviewed in the following section.

Classroom Studies of Teacher Movement and Space

Scholars in teacher education are beginning to advocate for a deeper understanding of how teachers move and use space in the classroom. In particular, these scholars highlight the critical role of teachers' movement and spatial decisions in shaping classroom instruction, student engagement, and overall classroom dynamics. Despite the growing interest in this topic, there are still only a handful of studies that explore the nuanced ways in which spatial factors influence teaching practices. In the following, I review three key areas that are central to this emerging field of research and my dissertation.

The first concerns the notion of spatial pedagogy. As first conceptualized by Lim et al. (2012), spatial pedagogy involves how teachers navigate and occupy different classroom zones (e.g., authoritative, personal, interactional, supervisory), through spatial choices that reflect and reproduce broader dynamics of power, attention, and participation. In other words, spatial pedagogy examines how the physical arrangement of the classroom and the teacher's positioning within that space can affect instructional strategies and teacher-student interactions. The second concerns the notion of groupwork monitoring (Ehrenfeld & Horn, 2020), which explores how teachers navigate the classroom to monitor students' activities, providing insight into how movement is tied to the facilitation of groupwork and student learning. Finally, I discuss uses of interaction geography as a methodological approach to transcribe and interactively visualize classroom video data over space and time.

Collectively, these areas not only inform my research but also contribute to a more comprehensive understanding of the complex relationship between space, movement, and pedagogy in the classroom.

Spatial Pedagogy

Spatial pedagogy can be understood as the ways teachers use space as a semiotic resource during instruction (Lim et al., 2012). Particularly, specific spaces in the classroom take on meanings of conversations, interpretations, and interactions between teachers and students related to their physical positioning. For example, Lim et al. (2012) identified four kinds of spaces in classrooms: (1) Authoritative Space (i.e., the front of the classroom), (2) Personal Space (i.e., space behind the teacher's desk) (3) Supervisory Space (i.e., between rows of desks) and (4) Interactional Space (i.e., next to a students' desk).

Expanding on this work, Martinez-Maldonado et al. (2020) incorporated positioning and proximity sensors to capture spatial behaviors. They used video and spatial mapping to analyze how embodied learning and spatial arrangements impact instruction. Through their methodology, Martinez-Maldonado et al. (2021) revealed that spatial arrangements and teacher positioning directly influence student engagement and collaboration, underscoring that physical space and its thoughtful utilization are vital for fostering an engaging learning environment. This study also introduced a technological approach to analyzing spatial dynamics, adding a new layer of understanding to spatial pedagogy. In other words, Maldonado et al. (2020) provide multiple ways to automate the collection of movement data and visually represent these kinds of spaces through representations of teacher's movement such as heat maps. Their work provides meaningful ways to examine spatial pedagogy and to generate a deeper understanding of embodied and spatial aspects of learning and instruction. Together, these studies emphasize that spatial awareness and strategic movement are critical tools for teachers. By understanding and utilizing these elements, educators can enhance classroom management, promote collaboration, and create more inclusive learning environments. The findings of these studies collectively suggest that spatial pedagogy is a key component of effective teaching and classroom engagement.

My research builds on these insights in several ways. Specifically, spatial pedagogy and related work has not been grounded in situative perspectives of teaching. Likewise, whereas spatial pedagogy has used static representations to describe teachers' movement over space, my analysis foregrounds teachers movement over space and time in relation to classroom conversation through dynamic and interactive visualizations. As a result this paper extends methods and frameworks researchers can employ to study teachers movement and spatial pedagogy in a maker space classroom setting.

Teacher Monitoring

Second, I extend work from Ehrenfeld & Horn (2020), who present a framework for analyzing teachers' monitoring routines during group work. Their work identified five aspects of teacher interactions with groups; (1) initiation of interaction, (2) conversational entry, (3) focus of the conversation, (4) how teachers exit the conversation and (5) the overall participation patterns. These aspects provided one way to consider how teacher's spatial movements within the classroom are related to patterns in conversations with students. By examining how teachers move and position themselves, Ehrenfeld & Horn (2020) provided insights into how spatial practices influence group-based learning. Their research suggests that teachers' spatial awareness is crucial for guiding students effectively in group settings, which often require nuanced support to facilitate productive collaboration.

My analysis extends this work by characterizing new kinds of teacher monitoring patterns while providing new methods that are capable of linking conversations and movement to expand the understanding of teacher monitoring as a responsive practice. The expansion of Ehrenfeld and Horn's (2020), work in analyzing teacher monitoring during group work offers a new depth to understanding how teachers' spatial and conversational approaches adapt responsively to student needs.

Interaction Geography

Finally, I extend recent work that has used a methodological approach called *interaction geography* to consider how teachers use movement and space to support classroom interaction and student learning across classroom lessons. Interaction geography offers dynamic transcription and visualization tools called Mondrian Transcription (MT) and the Interaction Geography Slicer (IGS) to interactively visualize the movement of people and things over space and time in relation to audio and video (Shapiro, Hall & Owens, 2017; https://www.interactiongeography.org). It integrates existing video-based methods such as interaction analysis (Jordan & Henderson, 1995), time geography (Hägerstrand, 1970), and movement transcription. Both the process of movement transcription and tools to dynamically visualize different forms of data offer a new methodological approach to conducting qualitative research about space and movement central to my work and study.

Figure 1 illustrates the kinds of visualizations and possibilities of this approach to visualize data about a teachers' use of movement and space across a 56-minute science lesson from the TIMSS 1999 video study.

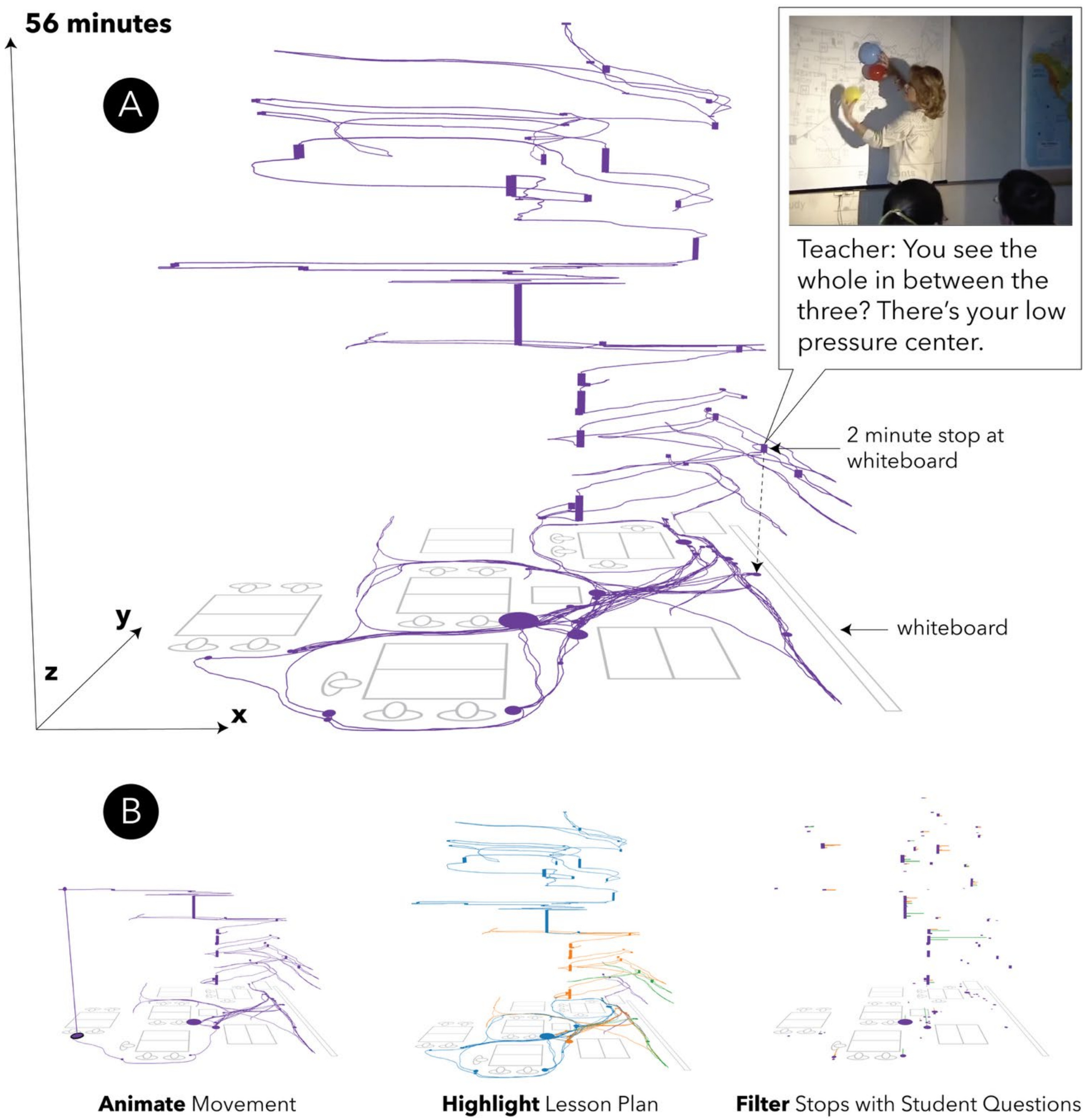

Figure 1. (A) IGS screenshot of a teacher's movement across **a 56-minute science lesson** in a 3D space-time cube. The floor plan shows the arrangement of tables, desks, the whiteboard, and students' positions at the beginning of the lesson. The teacher's movement is shown as a purple path over the floor plan and upward in a space-time view**. In the space-time view, the z-axis is time, and the x/y axes correspond to the floor plan.** Stops are depicted as purple circles on the floor plan, the area of which indicates the duration of the stop. In the space-time view, stops are shown as thick, straight lines whose length indicates stop duration. The figure also shows **how one can watch video and read conversation by clicking on the space-time view** video and conversation are shown during a 2-minute stop at the whiteboard. **(B)** IGS screenshots of the same data showing interaction techniques such as **animating** the teacher's movement, highlighting movement by code files that can be imported into the IGS (in this case of the lesson plan) and filtering data such as stops when students ask questions.

Important to my work are recent efforts to use interaction geography to characterize classroom interaction and teaching. For example, recent work by Shapiro et al. (2024) has used this approach to develop a framework to analyze classroom interaction consisting of four elements: trails, landmarks, material routines and monitoring patterns. Figure 2 and supporting animation video (https://youtu.be/wIyVYCuPxl0) shows a visualization from this study using this approach. The figure shows screenshots from the IGS that display six different teachers' movements across different classroom lessons. Teachers' movement is shown as a path over a floor plan of the classroom tilted in 3D perspective and also upwards in a space-time view where the z axis is time and the x/y dimensions correspond to the floor plan. Thicker lines in the space-time view indicate where and when teachers stop. Shapiro and colleagues highlight how such integrative and interactive visualizations provide crucial means to make selections from, code, rescale and develop interpretations from classroom video data to develop more integrative ways of characterizing classroom interactions as they evolve over the space and time of classroom lessons. As Horn et al. (2024) describe elsewhere, such visualizations also provide ways to support video-based professional practice for teachers to advance new conceptions about spatial and affective dimensions of learning and teaching in classroom settings.

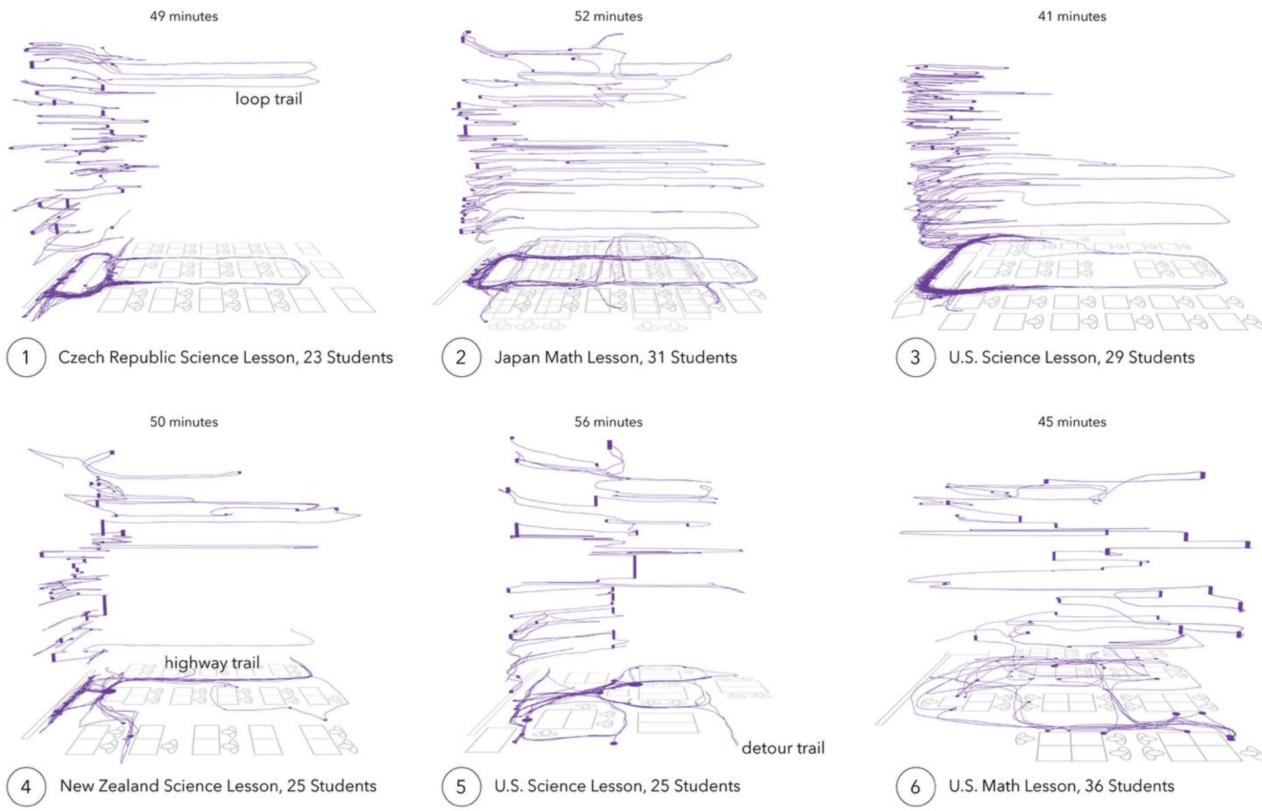

Figure 2. Interaction Geography Slicer screenshots that compare the movement of six teachers in different classroom settings. All data are set to the same spatial and temporal scales, and each case is labeled by country, content area, and number of students present. Whiteboards are oriented to the left on all floor plans. Annotations mark different movement trails. Video animation available at https://youtu.be/wIyVYCuPxl0

In summary, my study extends emerging ideas that foreground the role of space and movement as critical aspects of teaching and learning in classrooms. In particular, I advance studies of spatial pedagogy, extending methods to study spatial pedagogy and characterize spatial pedagogies in a maker-based classroom as opposed to traditional classrooms. Likewise, I explore how groupwork monitoring is enacted in a maker-based classroom and how such monitoring is similar and different to more traditional classrooms. Finally, I extend interaction geography as a method to study space and movement in classrooms, exploring the strengths and weaknesses of this method in a maker-based classroom context.

3. RESEARCH QUESTIONS

My study investigates the role of teacher movement in a maker-based classroom setting, where the strategic use of physical space and teacher interactions are integral to supporting student learning, collaboration, and engagement. My qualitative case study will answer the following questions:

1. How do multiple teachers coordinate their simultaneous movement to support learning in a maker-based classroom?
2. How do teachers' movement patterns evolve across different lessons and a complete semester?
3. What implications does an understanding of teachers' movement and use of space present for the physical design of maker-based classrooms?

4. CASE STUDY METHODOLOGY

A qualitative case study approach was adopted to explore how three teacher's physical movement and spatial patterns are employed to engage students in a maker-based course over the span of an entire semester. The purpose of this research is to investigate how educators leverage their physical presence, positioning, and spatial navigation to enhance student engagement and facilitate learning within a maker-centered educational environment.

Case study methodology, and specifically the exploratory case study design, was selected for its capacity to capture the richness, complexity, and contextual depth of real-world educational settings. Yin (2018) emphasizes that case study research is particularly valuable when the boundaries between the phenomenon and its context are blurred. This is often the case in education, where teaching and learning are not isolated activities but are deeply embedded within social, spatial, and material dynamics. An exploratory case study enables an in-depth investigation of these multifaceted interactions, allowing the researcher to retain the holistic and meaningful characteristics of real-life events. Such indistinct boundaries become even more evident in maker-based learning environments, where learning is embedded in physical, social, and material contexts.

Case study methodology provides an ideal framework for examining the dynamic, multimodal nature of learning in maker-based educational environments, where teaching and learning are enacted through real-world, creative, and hands-on practices. Drawing on Yin's (2018) conceptualization of exploratory case study research, this study examines a maker-based classroom as a real-world context in which teaching and learning unfold in ways that are continuously shifting. Lessons are analyzed as discrete *instructional episodes*, providing a detailed, contextually grounded view of pedagogical practices. These episodes illuminate how teaching and learning are supported, negotiated, and experienced in a maker-based classroom environment.

By closely analyzing these instructional episodes, my study seeks to develop insights and conceptual understandings about how teachers use space and movement to support learning. In doing so, it contributes to a deeper understanding of how educational practices emerge through the interplay of context, embodiment, and space, and contributes to shaping future empirical studies and theoretical frameworks within maker-centered education.

Study Context

The context of this study is a course, Inventing to Learn: Teaching and Learning with Maker Technologies, which is taught in a classroom where students learn to use a variety of technologies, including 3D printers, sewing machines, and microcontrollers. Three teachers, including a primary teacher and two teaching assistants (TAs) taught this course. The course integrates several competency domains: Practice and Pedagogies, Digital Fabrication, and Mechatronics (Cohen, J. D., Martin, L., & Ziegler, L. 2024). Instructional content for each domain was constructed into modules. The course is designed for students to explore various pedagogical strategies that leverage diverse technologies in a makerspace environment. The structure of the course encourages a non-competitive classroom that fosters student-centered and inquiry-based learning. Notably, the course is designed to be responsive to students with diverse interests in education and principles of making. The course is designed to activate student agency and active construction within making (Cohen et al., 2019).

Physical Classroom Space

The maker-based classroom adopted for this study is a dynamic, learner-centered environment intentionally designed to promote exploration, creativity, and hands-on engagement for both students and educators. Physically, the classroom mirrors a modern makerspace, equipped with a variety of digital fabrication tools including 3D printers, die cutters, sewing machines as well as traditional crafting and building materials. The physical design of the classroom supports students' and teachers' exploration through the positioning of tools and artifacts that creatively facilitate impactful hands-on learning. The space offers a collaborative learning environment centered around creativity, innovation, and experiential learning that supports both didactic, group, and hands-on learning activities.

The physical design of this maker-based classroom is shown in **Figure 3**. The classroom measures approximately 25 feet by 15 feet. The exterior walls have tables aligned that hold digital fabrication equipment, including 11 3D printers, 6 digital die cutters, a sewing machine, a CNC router, and a laser cutter. A focal and central set of tables in the center of the classroom holds about 20 seats and one interactive whiteboard hangs on the front wall of the classroom. There are storage containers aligned on the front exterior walls that contain other maker equipment such as microcontrollers, e-textile equipment, hand tools and consumables (Cohen et al., 2019).

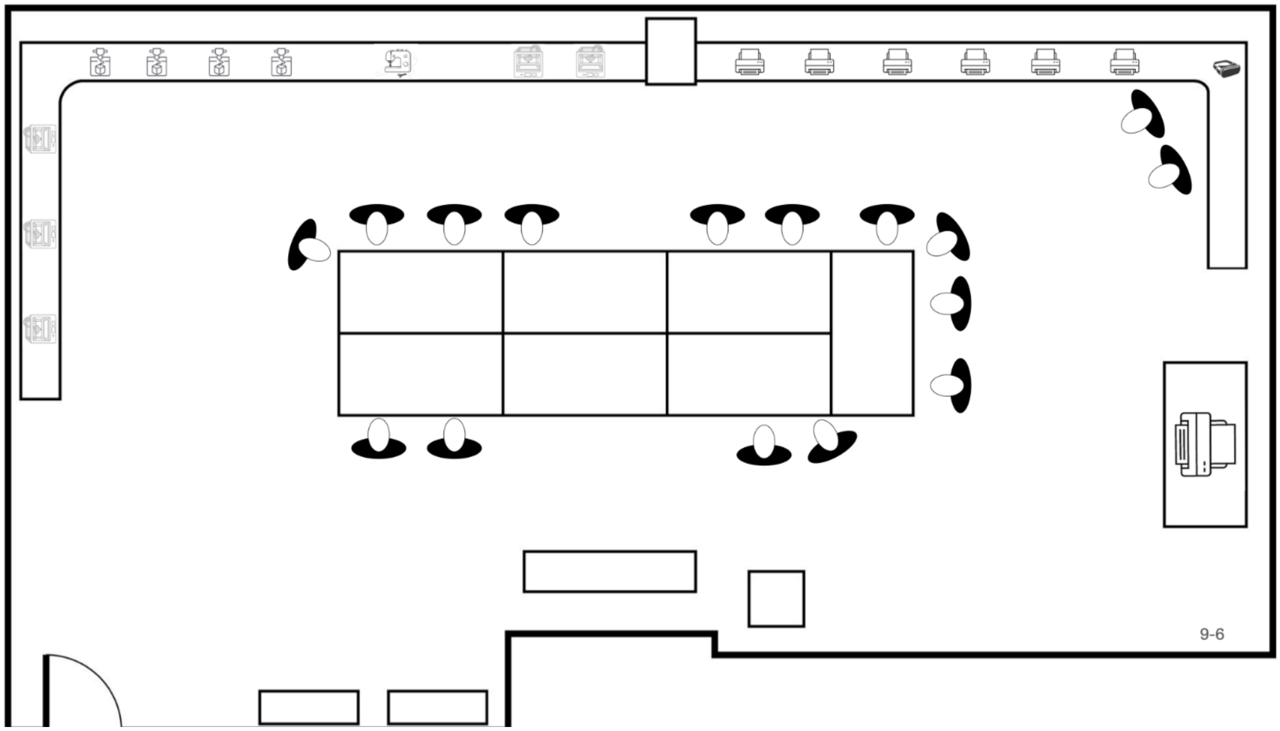

Figure 3. Floorplan of the maker-based classroom central to this study. The position of students is shown at the start of one lesson.

Data Collection and Sources

Over the course of one semester (Fall 2022), I collected multi-perspective video data of classroom activity within this classroom over a 12-week period. The class met once a week for approximately three hours, during which video recording of each session used three strategically positioned GoPro cameras. These were placed in distinct areas of the classroom: near the 3D printer, at the front of the room, and in the corner housing the VR station. This setup allowed for a comprehensive view of teacher movement, classroom flow, and the use of physical space. In addition to video data, I conducted ethnographic fieldwork to gain deeper insight into how teaching and learning were organized and experienced throughout the course.

One significant limitation of this data set is the lack of consistent, high-quality audio. Although some conversational exchanges can be interpreted through gestures, body orientation, and occasional audible cues, many spoken interactions, especially those in small groups or farther from the cameras are not fully captured. To address this limitation, I developed a coding strategy described later that interprets conversational engagement through movement patterns, spatial positioning, and other nonverbal cues, while recognizing the interpretive boundaries that result from the absence of full audio data.

Lesson Selection

From the 11 complete lessons recorded, I selected four primary lessons for inclusion in my analysis. These lessons were chosen to reflect a variety of instructional strategies and pedagogical approaches used across this semester. By focusing on these distinct instructional episodes, my study highlights the interplay between teaching practices and the spatial dimensions of the classroom.

My data reduction logic followed three main criteria. First, I selected lessons that were distributed across the semester to capture potential shifts in spatial patterns and classroom interaction over time. Second, I prioritized lessons that offered strong contrasts in how the lead teacher and teaching assistants employed spatial strategies during instruction. Third, I included only lessons where all three camera angles were fully functional and free of technical issues. The following lesson summaries illustrate the instructional flow and spatial practices unique to each setting, offering insight into how movement and space support instructional goals.

Lesson 9-6: Sensitivity to Design

This lesson focused on Sensitivity to Design, with students engaging in Thinking Routines as the primary activity. The session began with a 15-minute lecture delivered by Amari, providing foundational context for the activity. During this time, Malik prepared the classroom by organizing materials and ensuring all equipment was properly set up and functional. Following the lecture, the lesson transitioned into an independent work setting, where students worked exclusively on their computers to complete their assigned modules. Throughout this lesson the teachers maintained active engagement with students, offering support, guidance, and real-time feedback as part of the ongoing instructional process.

Lesson 10-4: Productive Failure

This lesson explored the concept of productive failure, using juggling as the central activity. Productive failure as a pedagogical approach encourages learners to engage with challenging tasks, allowing them to struggle and make mistakes as a means of deepening understanding and building resilience. I participated in this session both as an observer and as an active participant, providing a dual perspective on the classroom dynamics. The structure involved a whole-group activity initiated by a 15-minute instructional video on juggling techniques. Immediately following the video, students and the teachers practiced juggling together, creating a shared learning experience where initial failure was framed as a valuable step in the process of skill development.

Lesson 10-25: Maker Mindset

The focus of this lesson, titled Maker Mindset, involved activities that required students to watch videos and create lists as part of their engagement with the topic. The lesson was designed to support both whole-group participation and individualized instruction, with an emphasis on incorporating virtual reality (VR) technology to enrich the learning experience. It began with a 22-minute lecture and whole-class discussion led by Amari, which introduced the day's objectives and key concepts. After the lecture, the session shifted to a more interactive format, with the teachers providing personalized support as they moved throughout the classroom. Amari played a dual role as both facilitator and mentor to the graduate teaching assistants. Malik shadowed Amari to observe and learn instructional strategies, while Nia circulated with her laptop, offering real-time, hands-on assistance to individual students.

Lesson 11-8: Progress Reports

This lesson functioned as a makeup session, providing students with the opportunity to complete any remaining modules or use specific tools and machines in the classroom to finalize their assignments for the end of the semester. Unlike previous lessons, this lesson offered a more flexible and informal classroom environment. At the start of the session, Malik, Nia, and Amari immediately became active in their movement throughout the space. Amari, in particular, engaged directly with various artifacts and tools in the classroom, demonstrating their use to support student progress. The class had noticeably lower student attendance, which created a more open environment and allowed teachers greater physical mobility within the space.

5. DATA ANALYSIS

Overview

My study adopted a grounded theory methodology (Glaser & Strauss, 1967; Strauss & Corbin, 1998) alongside principles of interaction geography (Shapiro et al., 2024; 2025) to investigate teaching as a spatial and situative practice within the context of a maker education classroom. I used these methods to engage in an iterative and systematic process to deepen my understanding of how teachers navigate and utilize space within a maker education classroom context.

Importantly, grounded theory provided a flexible yet rigorous methodological framework that emphasizes the emergence of insights directly from the data, rather than relying on pre-established categories or assumptions (Charmaz, 2006). This approach facilitated an evolving analysis of teacher movement, spatial navigation, and pedagogical practice. Consistent with Charmaz's (2006) constructivist orientation, grounded theory encourages researchers to approach data with openness, fostering early analytic writing and exploratory interpretation. This iterative and reflexive process not only deepened my understanding of teacher movement and use of space, but also supported a theoretically grounded analysis of teaching as both a spatial and situative practice.

While this study draws heavily on the methodological tools of grounded theory such as iterative coding, memo writing, constant comparison. It does not aim to generate a fully developed grounded theory. Instead, I use grounded theory methods as an analytic strategy to illuminate patterns in teacher movement, spatial navigation, and pedagogical practice. As Charmaz (2006) notes, grounded theory methods can be adopted flexibly to support exploratory and interpretive analyses without requiring the construction of a formal theory. Given my study scope and focus, the goal is not to produce a comprehensive theoretical model, but rather to use grounded theory techniques to generate rich, data-driven insights that deepen understanding of teaching as a spatial and situative practice. This enables a careful, reflective analytic process that remains well-matched to the study's interpretive and descriptive purposes.

My analytical process followed a multi-phase approach. First, I transcribed teacher movement patterns from video records for each observed lesson, capturing spatial trajectories and physical interactions within the classroom environment. Second, I conducted an initial thematic analysis to identify emergent patterns and meanings. Following this, I conducted exploratory visual analysis, which involved mapping, visualizing, and interpreting spatial data with a tool called the interaction geography slicer (IGS) to further illuminate the relationships between movement and pedagogical practice. Subsequently, I refined preliminary codes and initial thematic categories to enhance analytical clarity and coherence. Finally, I established a set of core codes and categories that summarized my findings and supported the development of theoretical insights grounded in the data. In the following, I unpack each of these interrelated phases.

Transcription

To begin the data analysis process, I manually transcribed the selected classroom video recordings using the Mondrian Transcription (MT) tool. This tool enabled me to systematically trace each teacher's fine-grained movement patterns over a floor plan representation of the classroom, offering a spatially grounded and moment-to-moment account of instructional activity. Unlike automated alternatives which continue to remain imprecise and background qualitative transcription experiences, MT supports manual transcription through features such as fast-forwarding and rewinding that are highly detailed and capable of capturing nuanced and fine-grained movement and spatial patterns. The tool outputs a CSV file containing time-stamped positional data for each teacher, effectively serving as a transcript of their movement throughout the lesson. This fine-grained spatial data, combined with the tool's immersive nature, provided a foundation for capturing the embodied dimensions of instructional practice.

Engaging in this transcription process required repeated, attentive viewing of each lesson, which not only ensured accuracy but also deepened my familiarity with the classroom dynamics for each lesson. The technical and experiential nature of tracing movement allowed me to "feel" the motion of teachers—pausing, shifting, stopping, and orienting—thereby uncovering spatial and temporal dynamics that might otherwise go unnoticed. By watching each lesson multiple times and manually and efficiently tracing movements, I could identify subtle, yet meaningful, instructional behaviors and spatial patterns that reflected how teachers navigated their environments in relation to students, peers, and classroom artifacts.

Throughout this process, I wrote detailed analytic memos, pausing frequently to document emerging themes, questions, and connections across lessons. These memos supported reflexive engagement and served as an interpretive bridge between the raw movement data and broader pedagogical insights. In addition, I conducted an in-person observation of Lesson 10-4 as a participant-observer, further enriching my understanding of teacher movement through embodied, situated experience. As Shapiro and Silvis (2023) note, MT enhances traditional qualitative analysis by engaging researchers in an embodied mode of inquiry, illuminating the interplay between physical navigation and pedagogical intent. This multi-modal, inductive approach—combining manual transcription, memo writing, and direct observation—allowed me to analyze teacher movement not simply as physical positioning, but as a meaningful and dynamic component of teaching practice, embedded in the spatial and temporal rhythms of classroom life.

Thematic Analysis

Next, I conducted a thematic analysis that drew from my transcription experiences to identify initial categories related to teachers' movement, use of space, and interaction patterns within the classroom environment. This phase of analysis allowed me to generate emergent themes that showed how spatial navigation, teacher positioning, and embodied actions were closely tied to pedagogical intentions and classroom dynamics in a maker centered classroom environment. Through careful, iterative review of the video data and memos, I began to construct codes that captured recurring movement patterns, spatial orientations, and types of teacher–student engagement.

For example, to analyze instructional practices, I developed a set of codes to identify transitions between distinct phases of instruction. These phases included whole-group lectures, peer-pair discussions, independent group work, whole-class debriefs, virtual reality (VR) interactions, student-led activities, and the use of technological tools such as 3D printers, a sewing machine, and die cutters. As thematic patterns began to emerge, I closely examined how each teacher's movement patterns such as moving toward or away from student groups, positioning themselves at the front of the classroom, or remaining stationary were shaped by their instructional objectives and their real-time assessments of student needs, while also considering how teachers coordinated such patterns together.

Exploratory Visual Analysis

Next, I conducted exploratory visual analysis to develop a more detailed and comprehensive understanding of how teachers used space over time. Grounded in the principles of Interaction Analysis (Jordan & Henderson, 1995), this phase of the analysis supported the development, comparison, testing, and refinement of emergent analytical categories, with the aim of constructing concrete conceptual representations of teacher movement and spatial practice. Central to this process was the use of the Interaction Geography Slicer (IGS), a tool introduced by Shapiro et al. (2024; 2025) for visualizing classroom participation patterns and spatial trajectories. The IGS enabled me to dynamically visualize each teacher's movement across the classroom floorplan, offering a fine-grained temporal and spatial account of their interactions.

This approach to visual analysis emphasized the embodied and situated dimensions of teaching by allowing me to examine how teachers oriented themselves in relation to students, peers, and classroom artifacts. Through the IGS, I was able to visually explore and animate movement paths, identify recurring spatial routines, and attend to nonverbal aspects of interaction such as pauses, directional shifts, and proximity. For example, **Figure 4** shows a screenshot from the IGS of a piece of my data. One teacher's movement is shown over the classroom floorplan and upwards in a space-time view where the z-axis is time and the x/y dimensions correspond to the floorplan. Dots on the floorplan indicate specific locations where the teacher paused for at least five seconds while thicker lines in the space-time view indicated the duration of these stops. As movement unfolds over time, these patterns progress upward on the floor plan, revealing an evolving trajectory of teaching through movement patterns.

To prepare the data for use in the IGS, I imported a classroom floorplan image (in PNG or JPG format), synchronized classroom video footage (in MP4 format), and uploaded the CSV files generated from the Mondrian Transcription process. These CSV files were essential for visual analysis, as they contained time-stamped positional data for each teacher, enabling precise spatial tracking across the duration of each lesson. The integration of these multimodal data sources within the IGS allowed for ongoing comparison across lessons and teachers, facilitating an iterative and inductive analytic process consistent with the constant comparative method.

Ultimately, this phase of the analysis provided a robust foundation for identifying key trends, spatial shifts, and pedagogical distinctions in how teachers navigated and organized classroom space. By leveraging the capabilities of the IGS in conjunction with interaction analytic principles, I was able to construct a visual and conceptual map of spatial and mobile dimensions of pedagogy.

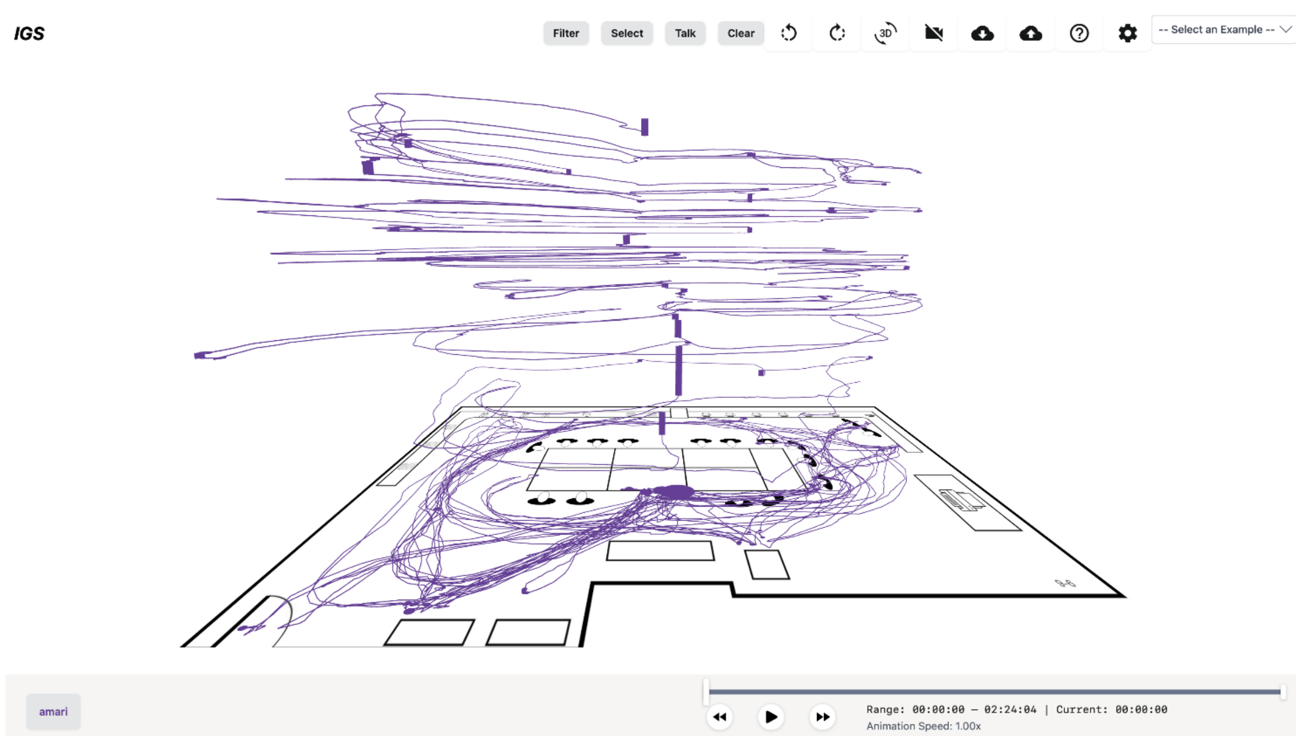

Figure 4. Screenshot from the IGS showing Amari's movement across lesson 1 (9/6), which lasted 2 hours and 24 minutes.

Code Refinement

Then, I engaged in a systematic process of code refinement, guided by detailed visual representations of each teacher's movement patterns across individual lessons. To begin, I generated broad comparative screenshots from the IGS to identify and categorize general spatial behaviors and instructional positioning. Subsequently, I iteratively refined analytic categories reviewing analytic memos, video, and field notes generated throughout the process. This process resulted in my development of five overarching analytic categories, which served to explore and contextualize teacher movement within and across all of the lessons for each teacher and organize several sub-categories.

These overarching categories are described and unpacked in detail below and include: (1) Teacher movement over space, (2) Stopping patterns in space, (3) Movement over space and time, (4) Stops over space and time, and (5) Pedagogical patterns over space and time.

6. RESULTS

Overview

I organize my analysis by presenting and interpreting a series of IGS visualizations of multiple teachers' movement patterns captured across each of the four distinct classroom lessons across a 4 month academic semester. These interpretations aim to offer a detailed and multi-faceted understanding of how multiple teachers navigate and utilize classroom space through their movement to facilitate learning, providing insights into phenomena such as how teachers position themselves, interact with students, and adapt their practices to meet the needs of diverse learners. They also draw both from my exploratory visual analysis using the IGS and my detailed transcription of each teachers' movement from classroom video.

Specifically, I organize my results into four distinct sections that focus on: 1) *teacher movement in space*, 2) *teacher stopping patterns in space*, 3) *teacher movement over space and time*, and 4) *teacher stopping patterns over space and time*. For each sub-section of my analysis, I present a visualization created with the IGS and then interpret this visualization to address my primary research questions.

Teacher Movement over Space

Figure 5 presents a series of IGS screenshots illustrating the distinct movement patterns of each teacher across each of the four classroom lessons. Each row corresponds to a specific teacher—Amari (lead teacher), Malik, and Nia—while each column represents a specific classroom lesson organized by date. The movement of each teacher is shown as a path where color is used to differentiate different teachers: purple represents the lead professor Amari, orange corresponds to Malik, and green indicates Nia's movement. Circles indicate periods of time when each teacher stops, with the area of circles indicating the duration of stops. As described previously, the positions of students at the start of each lesson are marked on the floorplan in addition to other particular spatial features of the classroom such as various tools and resources that include 3D printers, die cutters, a sewing machine, a designated area for the VR headset (used by students for virtual reality engagement), and a large printer.

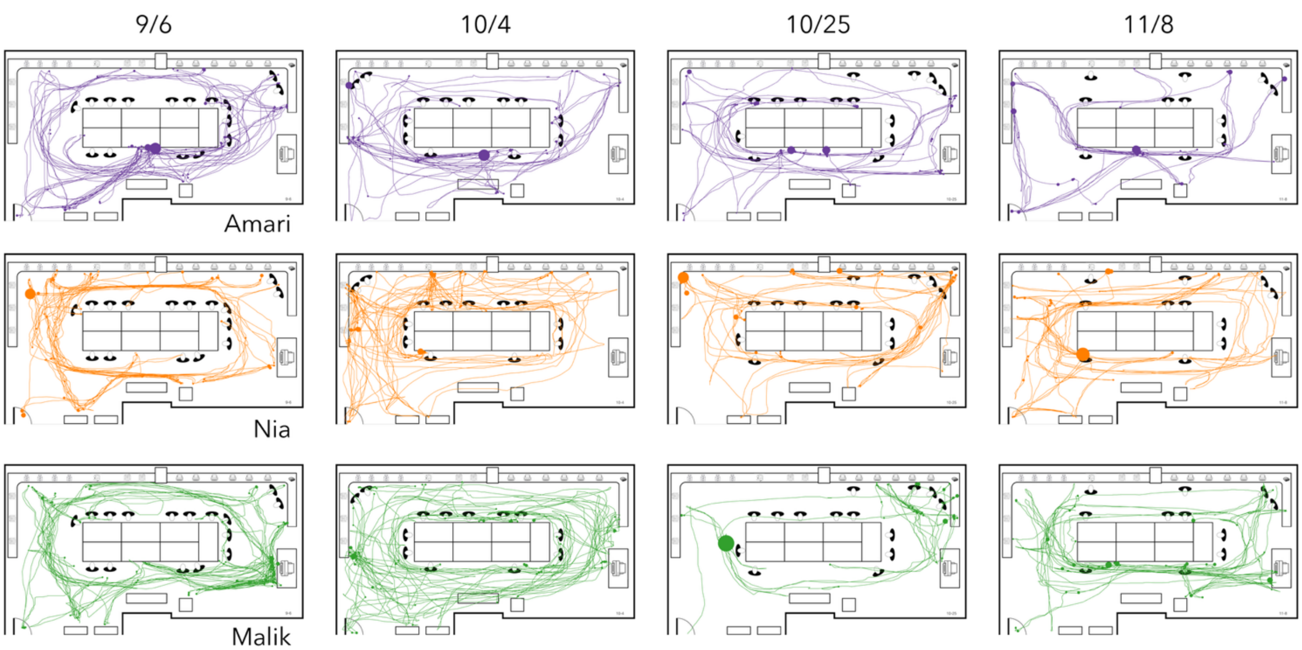

Figure 5. IGS screenshots of Amari, Nia, and Malik's movements across four lessons spanning a four-month academic semester. Movement paths are color-coded by teacher; stops are represented by circles, with circle area indicating stop duration. Student positions and selected materials/artifacts are shown at the start of each lesson.

Interpretation

Lesson 1. The topic of the first lesson depicted in the previous **Figure 5** (9/6) was sensitivity to design. This lesson began with an approximately 15-minute lecture style presentation from the lead teacher to introduce and frame the central concepts of the lesson. Subsequently, the class transitioned into approximately an hour and a half of structured groupwork and activities. Finally, at the end of the lesson, the lead instructor Amari re-convened the class in a lecture-style format to discuss key takeaways of the lesson. Thus, this lesson incorporated a variety of pedagogical techniques.

Amari's movement reflects his role as the lead instructor during this lesson. Namely, much of his movement is concentrated at the whiteboard and in a primary, authoritative position at the head of the central table in front of the class. This is indicated in the figure by the density of his paths at the front of the classroom near the whiteboard, as well as a significant duration of stops in these areas. Likewise, Amari's movement also reflects his efforts to visit all students and groups across the lesson as they engage in groupwork or structured activities. This is demonstrated in the figure by the repeated traversals of his movement paths around nearly all areas of the classroom where students are seated. During this particular class period, Amari exhibited more physical movement than in any other of the other lessons shown in the figure. This underscores his focus in this early lesson of the semester to engage with all students as they begin to acclimate with the course.

Malik and Nia's movement reflects qualitatively different patterns in comparison to Amari. First, their movement is not centered on the front of the classroom near the whiteboard, but rather in other areas of the classroom. In Malik's case, much of his movement is centered around sides of the classroom and areas of the classroom that hold artifacts such as 3D printers and where different student groups work across the lesson. In Nia's case, much of her movement is similarly focused on different parts of the classroom. Second, Malik and Nia each illustrate different kinds of movement patterns and ways they use different areas of the classroom. For example, Malik appears to move quickly across the classroom from one area to the next, while Nia (like Amari) appears to stop for significant periods of time at several areas of the classroom to engage with different students and groups as they work.

Overall, closer analysis of each teachers' movement across this first lesson (9/6) focused on sensitivity to design, highlights a clear division of roles amongst teachers. It is clear Amari is the lead instructor, as his movement reflects an authoritative spatial pedagogy (Lim et al., 2012) at key points and sequences across the lesson. Put differently, in this early lesson of the class, Amari is establishing norms, routines, and foundational interactional patterns that will support teaching and learning in this classroom over the semester. In contrast, Malik and Nia exhibit different kinds of supporting movements. Malik focuses his movement in different areas of the classroom, often moving quickly across the room to provide students with material support or address other issues identified by Amari. Nia's movement illustrates her efforts to mirror Amari's work to provide support to different groups and students across the lesson.

Lesson 2. Lesson 2 focused on the topic of productive failure and incorporated different kinds of experiential learning activities, which was unique in comparison to other lessons across the semester. The lesson began with a series of activities focused on juggling to engage students in constructivist approaches to considering productive failure. First, students watched a video on how to juggle. Subsequently, Amari, Malik and Nia distributed tennis balls to students for them to juggle providing support to students as needed to teach them how to juggle. This learning activity intentionally emphasized that there was no "right" or "wrong" way to juggle. Instead, the primary objective was to highlight how embracing failure and persistence in the learning process could ultimately lead to success. Students were encouraged to focus on rhythm, momentum, and iterative improvement, aligning with the broader pedagogical principles of experiential learning, where understanding is constructed through direct experience and reflection. Immediately following the juggling session, Amari brought the class back together for a 30-minute lecture that contextualized the activity, aiming to clarify how it relates to and influences the concept of maker-based education in teaching and learning. Finally, the class proceeded to engage in groupwork for the rest of the lesson.

Amari's movement across this lesson as shown in the previous Figure 5 highlights similarities and differences to his movement from the previous lesson 1. Similar to lesson 1, his movement across the floor plan highlights his use of the front of the classroom near the whiteboard as a central area of direct instruction, as indicated by significant stop(s) near this area. Similarly, during juggling activities and whole class groupwork his movement is focused in different areas of the classroom. However, there are notable differences. For example, he moves less in this lesson, and his movement is focused on fewer areas of the classroom in comparison to the first lesson. Closer analysis of his movement in the IGS and through manually transcribing his movement, illustrates his efforts to strategically position himself to interact with students as they need help and support while also finding vantage points where he can observe everyone's efforts (e.g., during juggling activities) to provide direct support. In this way, Amari's movements reflect efforts to maximize his presence during key periods of time in the lesson to support students.

Like Amari, Nia's movement in the 2nd lesson was similar and different in key ways in comparison to the 1st lesson. Figure 5 illustrates that her movement increased significantly in the 2nd lesson. Notably, she visited many of the same places she visited during the first lesson many more times as well as new areas of the classroom. She also circulated the classroom many more times. Like Amari, closer analysis with the IGS and manual transcription of Nia's movement highlights how her movement during this 2nd lesson reflected her efforts to position herself near specific students to offer targeted support as well as positioning herself in key vantage points to scan the room and assist students. Likewise, particular areas of the left side of the classroom where Nia concentrates her movement emerge.

Similar to Nia, Malik moved significantly more in this lesson than in the previous lesson 1. Figure 5 shows a tremendous amount of movement in comparison to the first lesson as Malik visited several of the same and new parts of the classroom as well as followed new pathways across the classroom to move between particular areas. Closer analysis highlighted notable aspects of Malik's movement. In particular, Malik's movement was more reactive, spontaneous, quick, and one directional in comparison to Nia and Amari. He often quickly traversed the classroom, rapidly changing directions and always going forward along a path to engage with students. Moreover, he often returned to specific vantage points or designated areas from which he could see and notice students, similar to Nia and Amari.

In summary, all teachers' movement across the second lesson illustrated similarities and differences to the previous lesson. Notably, while Amari's movement decreased slightly, Malik and Nia's movement increased significantly. Moreover, all teachers illustrated their use of concepts such as vantage points to observe and engage with students. Likewise, whereas Amari and Nia illustrated movements focused on observing the class and engaging at key points, Malik's constant and rapid traversals across the classroom demonstrate qualitatively different movement patterns to achieve the same purpose. Collectively, a theme that begins to emerge is Amari assuming more a supervisory role reflected in less and key strategic movements, while Malik and Nia assume more active roles as evidenced by significant growth and qualities of their movement in comparison to the first lesson. Finally, these movements are notably important to support key activities focused on productive failure.

Lesson 3. On October 25, 2023, the class session centered on self-directed learning with a specific focus on the Maker Mindset. The lesson was designed to foster autonomy, creativity, and engagement through various hands-on and independent learning activities. The session launched with a structured introduction, including a 7-minute video and a 15-minute lecture that provided foundational knowledge about the Maker Mindset. Following the lecture, students transitioned to independent learning activities, where they assumed full responsibility for their educational process.

Amari's movement throughout the lesson was more limited and deliberate, showing a balanced and intentional approach in choosing where and when to assist students. In contrast to Malik's more active style, Amari moved with restraint, only visiting the VR station approximately six times. His presence in different areas of the classroom appeared evenly spaced out, suggesting that he was selective in the moments he chose to intervene or provide guidance.

Malik's movement, on the other hand, played a more immediate role in driving the lesson forward. He began by heading straight to the front of the classroom to adjust the audio, ensuring that all students could hear the video clearly. After completing this quick technical adjustment, he returned to his seat and joined the rest of the class while the video played. Once the video ended, however, Malik's movement became much more focused around the VR station. He made repeated stops near the students working in that area, engaging with them consistently throughout the remainder of the lesson. His frequent presence there indicated a sustained focus on supporting and monitoring the activity taking place in that space.

Nia's movement patterns also reveal a significant balance of positioning in coordination with both Amari's and Malik's. She spent the majority of her time on the opposite end of the classroom, primarily near the sewing machine. This positioning allowed her to cover an area of the room that complemented the locations where Amari and Malik were stationed, creating a more even distribution of adult presence.

During many of her interactions with students, Nia chose to sit down next to them, offering direct, hands-on support for their learning tasks. This approach not only facilitated individualized instruction but also fostered a more comfortable and engaging environment for the students. Her choice to remain in close proximity to learners, rather than standing over them, seemed to encourage participation and focus, further enhancing the effectiveness of her assistance.

The lesson uniquely integrated maker-centered artifacts and resources, encouraging experiential learning. Students had access to tools such as a virtual reality (VR) system, a sewing machine, and a 3D printer, which enabled them to engage in manual, hands-on activities. These resources provided an opportunity for students to immerse themselves in the creation and exploration process. While some students actively utilized these resources, others opted to focus on independent computer-based modules, highlighting the flexibility of the session in accommodating diverse learning preferences.

Lesson 4 was held on November 8, 2023, which served as a designated make-up day, with the focus centered on Progress Reports. The primary objective of the session was to provide students with the opportunity to complete or revise any outstanding modules before the progress reports were finalized. This session stood out from typical lessons due to the timing of the whole-group discussion, which was conducted at the end of the class period rather than at the beginning. The class began with students being greeted by the primary teacher, setting a welcoming and structured tone for the day. After the greeting, students were prompted to direct their attention to assignments that required completion or revision. Unlike previous sessions, students quickly transitioned into their designated workstations, where they engaged in focused tasks. These workstations allowed for collaborative efforts, enabling students to work either, independently, in small groups or peer-to-peer to enhance learning and problem-solving. Each teacher demonstrated intentionality in their engagement, whether working on a task while students were active, interacting with one another, or independently completing work on the computer.

Dr. Amari’s movement throughout the observed lesson was largely stationary, with his primary position anchored at the front of the classroom. His approach to lesson delivery was laid-back and conversational rather than heavily instructional. The first 15 minutes of the session were spent seated at the front, engaging students in casual dialogue. During this time, he distributed progress reports, using the exchange as an opportunity to individually debrief students on their performance.

Once this task was completed, Dr. Amari returned to his original position at the front of the classroom, maintaining a central vantage point from which students could approach him for assistance. Students seeking help either walked directly to him or called out to gain his attention. His interactions were reactive rather than proactive, relying on student initiation.

Intermittently, Dr. Amari left his front position to address various needs in the room. These movements were brief and purposeful by retrieving items from cabinets, making small adjustments to classroom materials, or stepping outside the classroom to assist students who opted to work at desks located in the hallway. These movements did not follow a predictable pattern but were responsive to emerging classroom needs.

Malik demonstrated a steady and fluid movement pattern throughout the lesson, positioning himself strategically to be readily available for student assistance and to support Dr. Amari. His movement was not rigidly structured but rather adaptive to the flow of the classroom.

Notably, Malik frequently engaged in brief debriefing conversations with his peer, Nia, in between managing student interactions. His positioning during this session contrasted with previous observations in which he and Nia balanced opposite ends of the room. In this particular lesson, Malik tended to remain on the same side of the room as Nia. This change in positioning may be attributed to the nature of the activity, which did not require intensive safety monitoring or direct oversight of specialized equipment, such as the VR station used in prior lessons. Malik's movement appeared intentional in maintaining visibility and accessibility to students, though it lacked a repetitive or patterned structure. Instead, his presence shifted fluidly based on emerging needs within his proximity.

Nia primarily occupied the area of the classroom where the sewing machines were located. Her physical movement was limited in range, as she remained stationed in this section for the majority of the lesson. Most of her engagement involved providing extended, one-on-one assistance to individual students.

Her method of interaction followed a consistent pattern: upon receiving a request for help, she would acknowledge the student verbally, walk directly to their workstation, and engage in standing dialogue to clarify the need. She would then pull up a chair to sit beside the student, enabling close proximity for more hands-on support. After resolving the student's concern, she returned to her primary position which was near the front of the classroom next to Dr. Amari.

Her repeated sequence while acknowledging students, walking over, sitting beside them, providing assistance, and then returning to her original spot remained consistent throughout the lesson, indicating a deliberate and task-oriented movement style.

In summary, Figure 5 highlights unique movement patterns over space of each teacher as they evolve across a semester. Notably, aspects of how teachers coordinate their movement as a pedagogical strategy in a maker-based learning classroom environment begin to emerge. For example, one key finding suggests that as classroom norms and expectations are solidified, the primary instructor strategically stepped back from authoritative zones, empowering his teaching assistants to take a more active role in facilitating learning. This pattern underscores how teacher movement can be used to distribute and share authority and promote student-centered engagement in maker-based settings.

Stopping Patterns in Space

Figure 6 presents a series of IGS screenshots illustrating the distinct stopping patterns of each teacher across each of the four classroom lessons. Once again, each row corresponds to a specific teacher—Amari, Malik, and Nia—while each column represents a specific classroom lesson organized by date. Circles indicate periods of time when each teacher stops, with the area of circles indicating the duration of stops. These visualizations are useful for a variety of purposes including identifying *hotspots* or particular locations where teachers stop for longer periods of time or repeatedly across a lesson as well as supporting closer analysis to understand how stopping patterns reflect efforts to engage with students, oversee classroom activities, and support instruction.

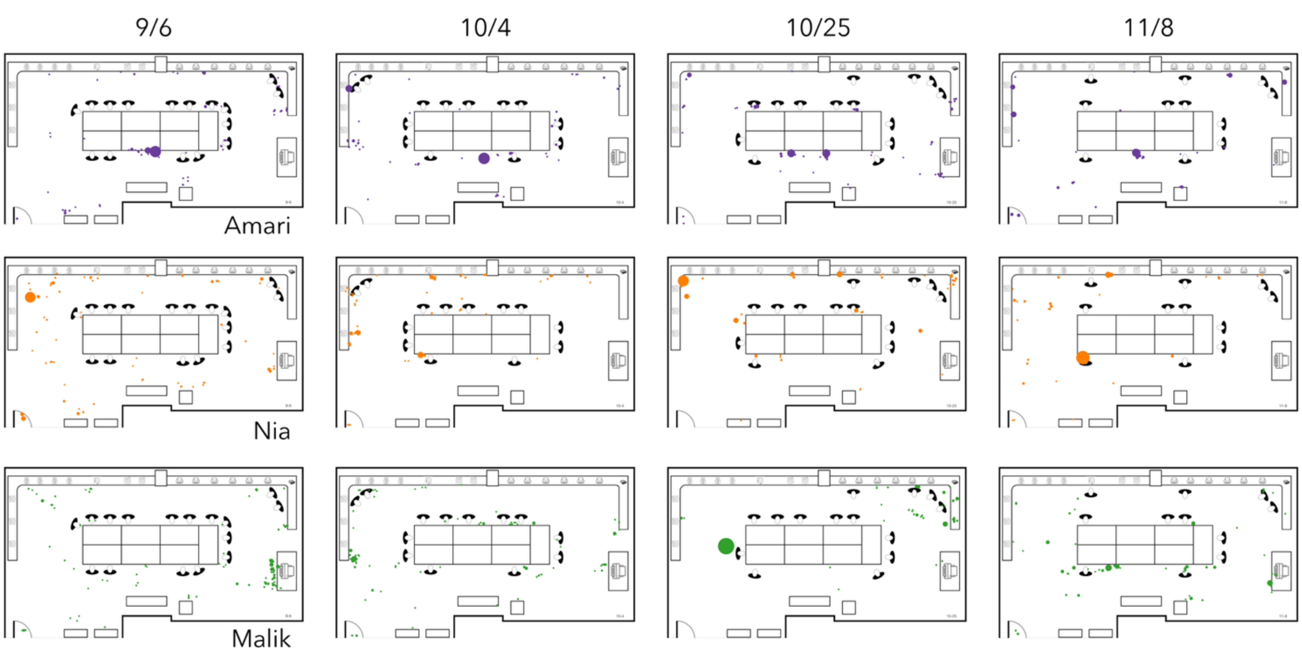

Figure 6. IGS screenshots of Amari, Nia, and Malik's stops across each of the four lessons. Stops are marked by circles, the area of which indicates the duration of each stop.

Lesson 1. Figure 6 underscores how Amari's stopping patterns in the first lesson are predominantly focused on the front of the classroom and a particular location at the head of the central table. These stops reflect Amari's efforts to center the class at the beginning of the semester and this particular lessons' focus on more lecture-based activities. Amari's stops during parts of this lesson focused on groupwork are also distributed across the classroom, further highlighting his efforts to distribute attention to various students and groups. The stopping patterns of Malik and Nia are distinctly different from Amari. Notably, their stops are not concentrated in the front of the classroom. In the beginning of the lesson, they assume background roles listening to Amari as he centers the topic for the day and begins to build classroom norms for the semester. As the lesson transitions to groupwork and similar to Amari however, Malik and Nia illustrate significant efforts to stop across several areas of the classroom where students and groups work. This highlights how they mirror Amari's efforts to support students and groups in this lesson.

Lesson 2. Figure 6 shows how Amari's stops similarly are focused on the front of the classroom and at the head of the central table. Notably, the number of stops and the locations of stops from Amari are significantly less than in comparison to the first lesson. In contrast, Malik and Nia's stops significantly increase both in time and in their location. Figure 6 highlights how Malik and Nia both engage in several longer stops as they work with particular students and groups (i.e., there are many more larger circles on the floor plan). Closer analysis with the IGS and manual transcription illustrates how Malik frequently used his laptop as an instructional tool while stopping to engage with students. His stopping patterns were characterized by frequent pauses while *standing*, during which he simultaneously interacted with multiple students. This approach allowed him to oversee and facilitate learning across a broader section of the classroom at any given moment. In contrast, Nia's stops were predominantly marked by *seated* interactions, where she positioned herself next to a single student at a time, offering more individualized support. This contrast in ways of conducting stops amongst teachers highlights how stopping patterns encompass distinct teaching strategies, with Malik employing stopping patterns that allowed him to quickly engage with students while being able to oversee other parts of the classroom, while Nia employs stopping patterns that are more concentrated and focused on one-on-one interactions by seating herself amongst students.

Lesson 3. Figure 6 illustrates how teacher cluster stops emerge in specific areas of the classroom, particularly around the use of the virtual reality (VR) space and activities occurring at the front of the room. The clusters in this lesson emphasize the engagement routines that are often taking place among areas of the classroom that center students' attention with artifacts or tools that support the learning process. Malik and Nia, both focus their attention on the students using the VR headsets and the classroom activities taking place in that area of the classroom. The lessons demonstrate how these concentrated stopping patterns gradually decrease, reflecting an evolution in teaching strategies and situational awareness.

For example, as shown in **Figure 6**, a cluster stop appears at the front of the classroom, positioned directly in front of the whiteboard during each of Amari's lessons. These clusters are represented as circles that increase in diameter, illustrating the duration of time the teacher occupied this space. The visual representation of these stopping clusters reflects moments of extended teacher-student interactions, where Amari engaged in direct instruction, posed questions, or addressed the class as a whole. The increasing diameter suggests prolonged stationary periods, likely corresponding to sustained instructional episodes or interactive discussions occurring at the front of the classroom.

Lesson 4. Figure 6 illustrates how Malik's stopping patterns occur more frequently on one side of the classroom, in contrast to the opposite side primarily occupied by Nia. This spatial distinction highlights a shifting dynamic in student engagement, with Malik concentrating his interactions in areas where students more actively sought his assistance, while Nia maintained a consistent presence on her side of the room. Early in the lesson, their pauses are more frequent and brief, focusing on setting expectations, ensuring students understand initial instructions, and addressing any immediate concerns. During this phase, they primarily scan the room, offering quick clarifications and positioning themselves in areas where students may require additional guidance.

Movement over space and time

Figure 7 presents a series of IGS screenshots, providing detailed visualizations of teacher movement not only through space but also over time. Like before, each screenshot is labeled by lesson date with rows corresponding to each teacher. All movement data is standardized to the same spatial and temporal scales to further support comparative analysis. In this representation, teacher movement is depicted as a continuous path overlaid onto the floor plan and extended upward in a space-time view. As described previously, in this space-time view, the x/y-axes correspond to the floor plan, while the z-axis represents time, enabling a three-dimensional analysis of movement patterns over space and time. Likewise, in this space-time view stops appear as thick, straight lines, the length of which corresponds to the duration of the stop.

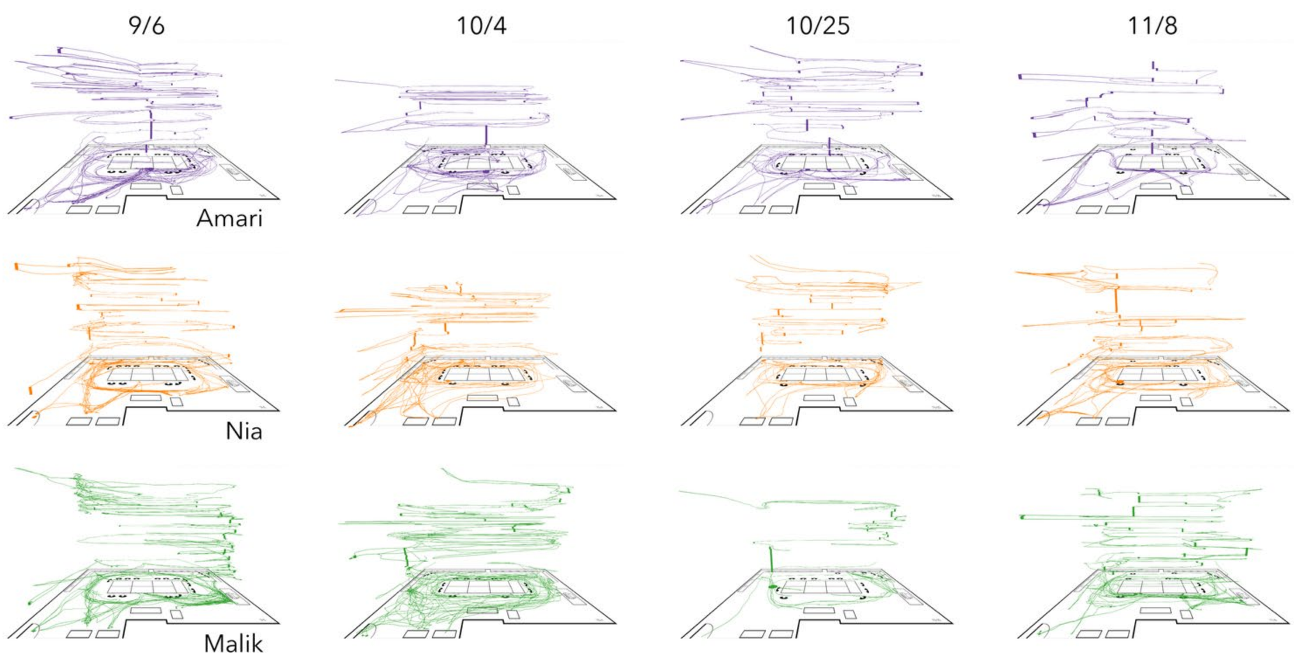

Figure 7. IGS screenshots of Amari, Nia, and Malik's movement over space and time across each of the four lessons. For each teacher and lesson, movement is shown across a floor plan and upwards in a space-time view, where the z-axis is time and the x/y dimensions correspond to the floor plan.

Interpretation

This figure supports interpretive analysis of teacher movement that focuses not only on where teachers move within the classroom, but how their spatial practices evolve over time within and across lessons. The visualization provides a clear comparison of teachers' movement patterns and how they shift over the course of the semester. In Lesson (9/6), paths are dense and circulatory, indicating frequent walking around the classroom. By lesson (11/8) movement patterns are lighter and more spatially anchored, reflecting reduced mobility. This reduction in mobility appears to reflect a gradual transfer of authority from teachers to students, signaling increased student autonomy and familiarity with classroom routines.

The figure also highlights notable differences in how each teacher enacts this shift. Amari's paths show structured, recurring routes, often returning to consistent zones across lessons, suggesting a stabilizing presence that anchors classroom focus. Nia's movements are more adaptive and student-centered, with frequent engagement across multiple groups of students in the classroom, particularly in high-traffic tool areas such as the 3D printer and sewing machine. Malik's paths reveal a balance between circulation and stationing, often positioning himself near the VR area while maintaining complementary spacing between himself and Nia.

This visualization underscores patterns of coordinated teacher movement across the classroom: Malik and Nia frequently position themselves on opposite sides of the room, a pattern clearly visible in the space-time movement views. This spatial distribution allows for balanced attention across students and groups, reducing redundancy and promoting equity in student support. This coordinated movement enables teachers to distribute instructional attention more effectively, ensuring comprehensive classroom coverage. Their movements rarely overlap, suggesting an implicit distribution of roles in which each teacher assumes responsibility for particular zones of the classroom.

The analysis further differentiates between two types of spatial activity: stationary presence and responsive circulation. High-traffic zones in the visualization such as the VR station, 3D printer, or sewing machine indicate areas where teachers frequently paused or clustered, often to monitor student use of complex tools or offer hands-on assistance. In this case, clustered movement refers to the teacher repeatedly moving within, or returning back and forth to, the same zones of the classroom.

For instance, when Malik is stationed at the VR area, Nia is often positioned at the opposite end of the room, near the 3D printer. This suggests an intentional allocation of space and attention, in which teachers maintain consistent stationing positions while shifting fluidly in response to classroom needs. These patterns also reflect pedagogical differences. Malik and Nia exhibit a highly responsive, student-centered movement frequently adapting their positioning in real time based on emerging student needs. Their flexible and fluid movement supports personalized interactions, spatial scaffolding, and accessible facilitation.

In contrast, Amari's movement is more structured and consistent. He often returns to familiar zones during key instructional phases, maintaining a steady presence that reinforces his instructional authority and helps anchor the focus of the classroom. This more stable positioning strategy may reflect an emphasis on stabilizing classroom norms and establishing spatial routines. Together, these findings illustrate the complex and intentional ways teachers use movement not only over space but also over time to coordinate instruction and support student engagement.

Stopping Patterns over Space and Time

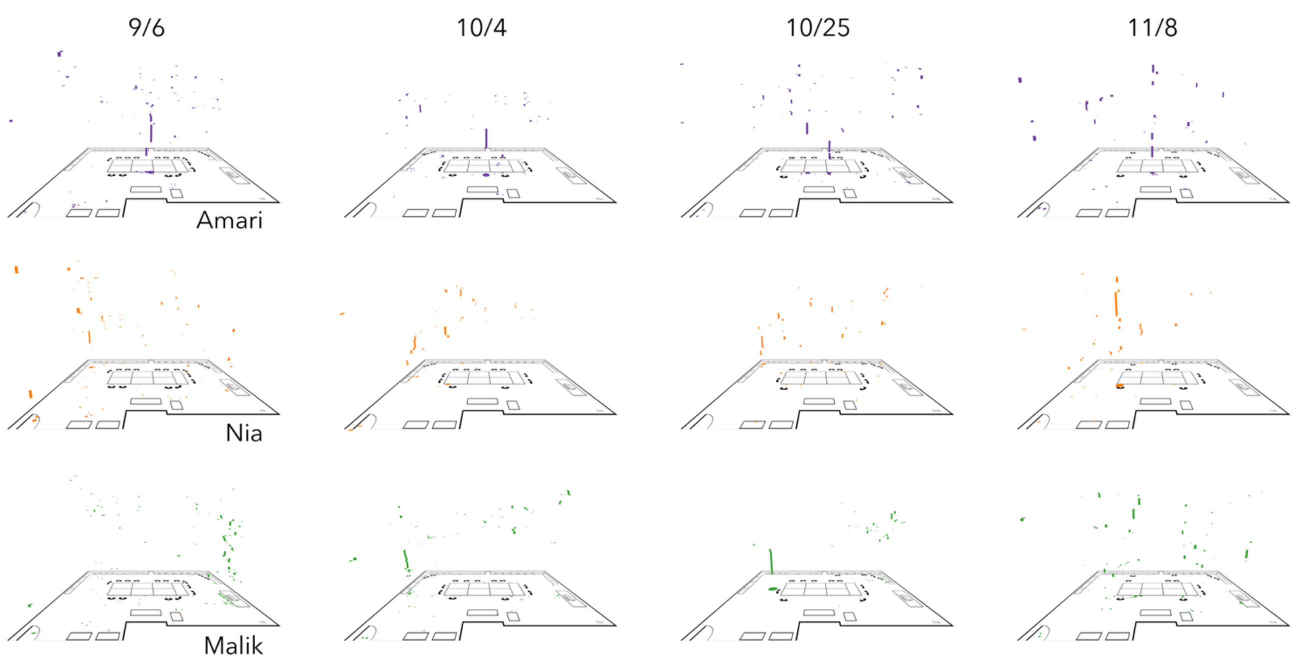

Figure 8. IGS screenshots of Amari, Nia, and Malik's stops over space and time across the 4 focal lessons. On the floor plan, circle size is stop duration; in the space-time view, line length is duration.

Figure 8 illustrates the temporal and spatial distribution of teacher stops, representing different locations where and how teachers pause extensively or repeatedly during lessons. Like before, each screenshot is labeled by lesson date with rows corresponding to each teacher. All data is standardized to the same spatial and temporal scales to further support comparative analysis. In this representation, teacher stops are depicted as circles on the floor plan, the area of which indicates the duration of stops, and as lines in the space-time view where the length indicates the duration of stops. As described previously, in this space-time view, the x/y-axes correspond to the floor plan, while the z-axis represents time, enabling a three-dimensional analysis of stopping patterns over space and time.

First, the figure makes visible the emergence of key instructional landmarks for each teacher. Amari's stopping patterns are consistently distributed across the classroom, with a concentration of medium length stops in central locations complemented by shorter stops around the periphery. This even spatial distribution suggests a deliberate attempt to maintain consistent access and oversight throughout the room as the lead teacher. In contrast, Nia and Malik's stopping patterns are more spatially differentiated. Their primary stop zones are located along the sides of the classroom near the 3D printers for Nia and the VR stations for Malik corresponding to areas where they provide specialized, hands-on support. While these patterns might appear coordinated, the figure suggests a more organic and responsive distribution of presence. Their stops align with students' evolving needs, reflecting an emergent, rather than pre-planned, spatial strategy.

Second, temporal trends become apparent when comparing lessons across the semester. In the earlier lessons, all three teachers exhibit a high number of short duration stops, indicative of frequent transitions, active monitoring, and high mobility. These short stops likely reflect the need to scaffold new classroom routines, manage student transitions, and provide continuous support. As the semester progresses, however, the frequency of short stops declines. Instead, teachers increasingly anchor themselves in specific zones for longer durations, signaling a shift toward more stable, targeted support as students become more autonomous. This reduction in movement once again underscores the role of teacher movement in scaffolding independence and distributing instructional authority over time.

Third, the visualization provides insight into the variation in stop duration across teachers and locations. While very long stops are relatively rare, medium length stops dominate the patterns for all three teachers. These sustained pauses often occur in high-engagement zones such as near tool stations or group work areas where extended presence enables deeper instructional interaction. Notably, each teacher also exhibits a few distinct long stops at consistent locations across lessons, suggesting the development of individual spatial routines or anchoring points within the classroom.

Taken together, these stopping patterns offer a nuanced view of how teacher movement functions in a maker-based classroom learning environment not only to monitor and manage, but to embed support in space and time. Stops are not simply pauses; they are pedagogical acts, signaling attentiveness, scaffolding, and presence. The evolution of stopping behavior over the semester reflects broader shifts in instructional strategy, student autonomy, and the co-construction of learning space.

7 DISCUSSION

To review, my analysis integrated a grounded theory approach alongside methods of interaction geography to explore how multiple teachers used their movement and space to support student learning across a semester in a maker-based classroom. In the following I synthesize my analysis to further address each of my first two primary research questions. Subsequently, I address my third research question by unpacking key implications of this study for different audiences.

Research Question 1: Understanding How Teachers Coordinate Movement to Support Learning in a Maker-Based Classroom.

My analysis identifies two key ways through which teachers coordinate their movements to support learning in a maker-based classroom: their distinct roles and their use of spatial pedagogy.

***The Influence of Roles on Teacher Movement*.** First, the three teachers in my study demonstrated distinct movement patterns across classroom lessons that reflected their unique roles. Amari primarily adopts an overseeing role, serving as the lead or primary instructor, offering overarching guidance and support for students. His presence is characterized by a desire to be seen, yet as opposed to constantly engaging students in interaction he carefully waits for cues before engaging, often positioning himself in locations easily accessible to students. This reinforces his role as an overseeing figure in the classroom who provides structured guidance to students who need help.

In contrast, Malik and Nia demonstrate more proactive movement patterns that align with their roles as secondary instructors or teaching assistants. Their movements are intentionally and continually focused on providing targeted support to students to foster a personalized and responsive learning environment. By continually engaging with students, they enhance the learning experience, ensuring that individual needs are met as they arise. Moreover, they often cede authority to Amari during periods of whole group lecture or synthesis as their movement slows and they position themselves towards the back or sides of the classroom.

It is worth noting that having multiple instructors working simultaneously in a single higher education classroom is relatively rare. Unlike K–12 environments where resource teachers, paraprofessionals, or co-teachers are more routinely integrated college classrooms typically rely on a single lead instructor. When larger instructional teams do appear in higher education, they are generally limited to specialized programs, laboratory-based courses, or classes that intentionally employ collaborative or peer-supported teaching models. Acknowledging this context highlights how distinctive the instructional arrangement in this study is and helps explain why the teachers' movement patterns hold particular analytical importance.

The Influence of Collective Spatial Pedagogies. Each teacher's movement patterns are shaped not only by their roles but also by the design of the classroom space and their spatial pedagogies. Put simply, the physical layout of the classroom plays a crucial role in how teachers in my study navigate and interact with students, while their movements and use of space should be understood not as isolated spatial pedagogies, but as part of *collective spatial pedagogies* embedded within the social and material dynamics of the classroom.

Each teacher strategically patrols, observes, and provides assistance in specific regions of the room, with their movements coordinated to match different phases of the lesson and one another. For example, Malik and Nia often separate during certain instructional activities, maximizing their ability to engage with students in different areas. However, when Amari begins a lesson or takes on a lecturing role, Malik and Nia often converge, signaling a shift in focus to whole-class instruction. Moreover, during groupwork Malik, Nia, and Amari's movements are typically coordinated to provide students with support in different classroom areas and in ways that actively or passively engage students. This spatial coordination is not incidental but a key aspect of their collective spatial pedagogy using the design of the space to facilitate different types of interaction and optimize support for students. By aligning their movements with the structure of the lesson, the teachers ensure that instructional resources, both physical and human, are distributed effectively across the room, allowing them to address the diverse needs of students in real time.

In summary, my analysis provides insights into how teachers coordinate their movement to support learning in a maker-based classroom. Importantly, my analysis underscores how in open-ended and unstructured learning environments like maker-based classrooms, teacher movement plays a critical role in facilitating learning. Rather than relying on static, front-of-class instruction, teachers in these spaces move fluidly throughout the room, engaging with students in ways that reflect the values of exploration, collaboration, and student agency central to maker education. This supports maker-based researchers in particular such as Halverson and Sheridan (2014) and Cohen et al., (2017), who emphasize that maker learning environments prioritize student-driven inquiry, requiring teachers to adapt their roles—often acting as facilitators or co-learners rather than direct instructors. In such settings, teacher mobility becomes a mechanism for informal assessment, scaffolding, and encouraging creativity.

Similarly, extending ideas by Ehrenfeld and Horn (2020), my analysis underscores how teacher movement helps shape the overall classroom environment, including who holds power and how relationships are built. This was evident in my observations. Teachers were not just moving around the classroom to control behavior or check on student progress; rather, they used movement to create a more equitable and supportive classroom atmosphere. For example, beyond the analysis shared above, when a graduate assistant sat next to a student instead of standing over them, or stayed nearby without immediately jumping in, they shifted from being an authority figure to becoming a learning partner. These small choices in movement helped break down traditional power dynamics and encouraged more open, collaborative learning.

Research Question 2: Understanding How Teachers' Movement Patterns Evolve Across Different Lessons and a Complete Semester.

My analysis identifies two key sets of findings about how teachers' movement patterns evolve across classroom lessons over a complete semester. First, my analysis shows how teachers' spatial pedagogies shift in tandem with their evolving instructional roles. Second, my analysis helps describe a set of spatial patterns and concepts that extend prior research and emerge through my analysis across multiple lessons and multiple teachers to offer new insight into how spatial pedagogies operate longitudinally within complex, collaborative learning spaces like maker-based classrooms.

Shifting Instructional Roles and Movement. In my study, as students become more active participants in shaping their own learning across the semester, there was a noticeable transition in each teachers' movement that reflected a shift in their roles from directing instruction and actively guiding students to more passively observing students. For example, early on, Malik and Nia are highly mobile, frequently adjusting their positions to engage with students, offer support, and direct learning. However, by the later lessons, their movements become more purposeful and restrained, reflecting a gradual ceding of authority to the students. This shift in their movement appears to correspond with a growing confidence in the students' ability to take on greater responsibility for their own learning. Similarly, Amari's movement decreases as students gain more autonomy in the classroom, marking a transition from a primary instructional role to one of oversight and strategic support. Collectively, the teachers' movement patterns mirror their changing role in the classroom: from active instructors to mentors who support and empower students as they assume greater control over their learning journey.

These findings expand upon situative and sociocultural perspectives on teaching by underscoring how teaching is a situative and spatial practice. Here, movement functions as a form of participation. Early teacher movement supports novice students' legitimate peripheral participation, while later reductions in movement signify a ceding of authority as students become more central participants. In this way, teacher movement and use of space both shapes and reflects the evolving social organization of the classroom.

My analysis also identifies recurring spatial patterns that extend and deepen existing theories of spatial pedagogy (Lim et al., 2012; Martínez-Maldonado et al., 2022), groupwork monitoring (Ehrenfeld & Horn, 2022), and frameworks for understanding teacher movement within single classroom lessons through concepts such as trails, material routines, circulation patterns, and landmarks (Shapiro et al., 2024). My study affirms the relevance of these theories and concepts, showing how teachers in a maker-based classroom exhibit similar practices when facilitating groupwork, engaging with students, and managing classroom interactions.

However, my analysis builds on this work by tracing how such spatial activity unfolds not just within single lessons, but across multiple lessons and across multiple instructors within the same classroom context. This longitudinal and multi-teacher perspective reveals patterns of spatial coordination and pedagogical alignment that suggest a shared repertoire of spatial practices evolving over time. In doing so, my findings introduce several new concepts to characterize these cross-lesson, cross-teacher dynamics summarized below:

- ***Expansion or Contraction of Movement Zones***: Teachers vary the range of their movement over time, either broadening their spatial coverage or narrowing it to specific student groups or areas of focus depending on instructional goals.
- ***Spatial Relinquishing of Authority***: A gradual withdrawal from central movement zones corresponds with increased student agency and the redistribution of instructional authority.
- ***Classroom Norm Internalization Through Space***: As students internalize classroom

expectations, teachers rely less on proximity or movement to enforce norms, allowing spatial cues to become part of the classroom's cultural infrastructure.

- ***Vantage-Point / Landmark Scanning***: Teachers use recurring positions—often near central landmarks—as vantage points to observe, monitor, and regulate the flow of classroom activity without direct intervention.
- ***Proximity-Based Scaffolding***: Strategic physical proximity is used to scaffold student understanding, with teachers moving closer to signal attention, redirect focus, or co-construct learning in the moment.
- ***Distributed Spatial Coverage***: Movement is collectively distributed among multiple teachers, enabling broader classroom groupwork monitoring and support while reducing redundancy.
- ***Spatial Consistency***: Teachers develop spatial routines or anchor points that serve as stable components of their pedagogy across time, helping students interpret movement as meaningful instructional signals.

8. IMPLICATIONS

Research Question 3: Understanding implications of teachers' movement and use of space for the physical design of maker-based classrooms.

This study offers several important implications for understanding the role of teacher movement and spatial practice in collaborative, open-ended learning environments like maker-based classrooms, directly addressing my third research question. Below, I outline key implications for four target audiences: maker-based classroom researchers, researchers using interaction geography, teacher educators, and classroom designers and architects.

Maker-Based Classrooms

My analysis and findings underscore that teachers' physical movement is not incidental but can be central to how they support student learning, monitor activity, and distribute attention in maker-based classrooms. My analysis demonstrates that shifts in movement patterns often correspond with broader shifts in pedagogy, such as increasing student autonomy or the redistribution of instructional authority among teachers and students. These findings suggest that maker-based classroom design should better accommodate and even anticipate such dynamic spatial practices.

Specifically, my work points to the need for physical maker-based classrooms that: (1) support fluid movement and adaptable zones for instruction and observation, (2) enable visual access and oversight from multiple vantage points, (3) consider the needs of co-teaching teams who may coordinate spatially over time, and (4) encourage the use of space as a pedagogical resource that evolves across a unit or semester—not just within a single lesson.

Interaction Geography

My dissertation extends the analytic scope of interaction geography as a visual and qualitative research method, by using it to analyze multiple teachers' movement and spatial practices across a full semester of instruction. Previous research has often used interaction geography to visualize a single teacher's movement within an individual lesson. In contrast, my study demonstrates how dynamic interaction geography visualizations, when combined with manual transcription methods like Mondrian Transcription, can reveal broader patterns of pedagogical change over time, across contexts, and among teaching teams.

This methodological expansion illustrates both the potential and limitations of qualitative spatial analysis tools. On one hand, it shows the strength of combining fine-grained, manual movement data with time-based spatial visualization to interpret instructional patterns. On the other, it underscores the need to further supplement such work with other kinds of data and research methods to triangulate research findings.

This study thus contributes to a growing toolkit for qualitative researchers seeking to analyze spatial practice in complex classrooms and encourages further innovation in visual, embodied, and temporal methods of interaction geography analysis.

Teacher Education and Professional Learning

My findings and analysis also contribute to an emerging body of scholarship that emphasizes the spatial dimensions of teaching and learning. While previous studies have focused on momentary decisions or teachers' movement and use of space within a single lesson, my study reveals how multiple teachers movement is a sustained and evolving practice, tied to broader pedagogical goals, classroom norms, and shifts in instructional roles over time. Put differently, my work has implications for understanding teaching not only as a situative practice, shaped by interaction and context, but also as a spatial practice—actively constructed through teachers' physical presence, use of space, and movement.

Such insights offer several implications for teacher education and professional development that include:

Reframing movement as pedagogy: Teachers can be encouraged to view their own movement patterns not just as functional but as central to how they engage learners, distribute authority, and support student autonomy.

- **Fostering teachers' reflective practice on spatial pedagogy**: The tools and methods used in this study could be incorporated into video-based reflection or coaching models, helping teachers analyze their use of space and how it supports or hinders learning.
- **Preparing teachers for team-based teaching**: As co-teaching and instructional collaboration become more common, the tools and methods used in this study could support training for educators on how to coordinate teaching spatially—e.g., how to divide zones, shift roles over time, and maintain awareness of shared instructional goals while moving through space.

Designers and Architects

Finally, this research has implications for the broader design of classroom learning spaces and environments. Notably, as schools continue to experiment with open-ended, collaborative, or co-taught models, classroom designers must take into account how teachers move through space—not just to manage logistics, but to enact pedagogy. My findings and analysis, including the visualizations produced through this work, can inform efforts to (1) create spatial affordances that accommodate multiple teachers and evolving instructional roles (e.g., Young & Cleveland, 2022), (2) design with long-term movement patterns of teachers in mind, not just with a focus on single lessons, (3) support visibility, accessibility, and flexible classroom spaces that facilitate and empower diverse interactions (e.g., Ellis & Goodyear, 2018), and (4) consider how spatial classroom design and teaching shape one another over time.

9. LIMITATIONS

This study has several important limitations. First, the research design focused exclusively on teacher movement within the classroom. As a result, the findings present a one-dimensional perspective of instructional practice that emphasizes teachers' physical movement, presence, and spatial navigation. While this focus offers valuable insights into how teachers utilize space, movement, and position themselves in relation to students and instructional tools within a maker education context, it does not account for how students interpret, respond to, or are influenced by these movements. Future research should consider incorporating accounts of both teacher and student activity to more fully capture the relational dynamics that shape classroom teaching and learning.

Second, the study relied on video records and methods of interaction geography to visually map teachers' movement and use of space. Specifically, the study relied on mondrian transcription and the interaction geography slicer to transcribe and visualize teachers' movement and use of space from classroom video records. Audio recordings were not analyzed, and other forms of data such as interviews with participants were not collected. As a result, the study provides limited insight into several crucial aspects of classroom interaction and communication, as it does not capture spoken interactions or the verbal and interpersonal responses of others in the classroom. This absence of communicative data also constrains interpretation of movement patterns and their potential significance within the broader context of the classroom activities that were taking place during each lesson. Future research should further integrate video analysis and methods of interaction geography alongside other qualitative, quantitative, and mixed-methods approaches to better characterize the multi-faceted dimensions of teachers' movement and spatial use.

Third, the research was conducted in a single, highly specific maker-based classroom. This setting emphasized hands-on, project-based learning, open-ended exploration, and the integration of digital and physical tools. While the physical layout of the classroom offers rich opportunities to observe embodied teaching practices and spatial movement in a student-centered context, the focus on a single, unique context limits the generalizability of this work. Notably, the physical layout, instructional approach, and overall learning environment of this classroom may differ significantly from other maker-based or traditional classrooms. Consequently, the insights derived from this study should be interpreted as context-specific rather than widely transferable. To develop a more comprehensive understanding of teacher movement and spatial practices, future research should explore a broader range of maker-based, educational, and classroom settings with varying classroom designs, teaching models, and learner demographics.

Finally, the analysis was based on four selected class sessions from a larger semester-long dataset. Although this sampling strategy allowed for an exploration of changes over time, it inherently reduced the complexity of classroom life and omitted significant interactions and patterns. Future work should explore more comprehensive or longitudinal sampling approaches to better capture the evolving nature of movement and spatial activity in such settings.

10. CONCLUSION

In summary, my dissertation used qualitative methods and interaction geography to visually analyze and map spatial pedagogies in a maker-based classroom, addressing three primary research questions focused on teaching as a situated and spatial practice. The findings show that coordinated movement among multiple teachers fosters equity by balancing attention across classroom zones, differentiating instructional roles, and ensuring that all students have equitable access to support. My analysis highlights how both circulation and stopping are deliberate pedagogical practices: movement enables broad classroom coverage and responsive interaction, while pauses create opportunities for sustained, individualized engagement. Teachers' spatial roles emerged through implicit distribution, with some establishing consistent presence in specialized areas and others circulating fluidly to adapt to shifting student needs.

Overall, my dissertation underscores the importance of movement as a pedagogical strategy, illustrating how coordinated teacher movement fosters equitable participation, and identifies how spatial roles are negotiated through patterns of distribution. These insights demonstrate that teacher movement is not merely logistical but a central routine that shapes engagement with learners, the distribution of authority in the classroom, and the cultivation of student autonomy in teaching and learning. Beyond the classroom, the findings also serve as a resource for designers and architects, offering new ways to consider how learning spaces can support pedagogical intent. Collectively, this work advances teacher education, maker education, and visualization research by developing concepts and methods to better study and represent spatial pedagogy.

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