Traveling through spatial repertoires and mathematics: Dialogic nature of physics discourse practices and socialization activities

A Dissertation
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Adviser: Dr. Kendall A. King

August 2020

Acknowledgements

This dissertation project would have not been possible without the support of all my study participants across three field sites, including The Center for Educational Innovation, The School of Physics and Astronomy, and The College of Science and Engineering. I want to especially thank my focal international graduate assistant participants, Gina, Kelly, and Ian, and their undergraduate physics students, for their support and active participation.

I am fortunate to have had incredibly supportive mentors. I am grateful to my adviser, Dr. Kendall King, who has provided me professional advice throughout my program of study and collaboration opportunity that have helped expand my research horizons. I am thankful to Dr. Cynthia Lewis for her guidance that has helped me develop and deepen my knowledge of ‘critical,’ ‘discourse,’ and ‘analysis’ aspects of discourse-in-action. I am grateful to Dr. Elaine Tarone for her insightful and constructive comments on an earlier draft of this dissertation. Elaine’s feedback was thought-provoking and has helped me tremendously at different stages of my writing. I owe gratitude to Dr. Susan Staats with whom I have had numerous discussions on my conversation and discourse analysis of physics socialization activities among linguistically and culturally diverse populations. I am thankful to have had the benefit of Sue’s interdisciplinary expertise on critical approaches to mathematics discourses and classroom interactions.

I am thankful to all the other applied linguists who have mentored me in various ways: Dr. Laura Ahearn, whose linguistic anthropology class at Rutgers University led me to the field of Language Socialization. Dr. Jean Wong, Dr. Hansen Zhang Waring, and other members of the LANSI Group at Teacher’s College at Columbia University led me to the field of Conversation Analysis. I am also grateful to the editors of the two special issues to which I contributed, Drs. Bal Sharma, Suresh Canagarajah, Sarah Braden, and Andrea Leone-Pizzighella, for their insightful and constructive comments on my journal papers.

I want to thank my parents for their faith in me and for their endless support and encouragement. I also thank my younger sister and brother for keeping me motivated and moving forward.

Dedication

I dedicate this dissertation to my family. Thank you for inspiring and enriching my language socialization with your language socialization.

Abstract

Language socialization research examines how situated discursive practices mediate socialization activities, and how members from diverse linguistic and cultural backgrounds participate in socialization activities to develop disciplinary expertise and membership. Bringing together Bakhtin's (1981) dialogism of 'chronotope' and 'heteroglossia' and a multimodal conversation analysis method, the present dissertation study builds on and extends this research by examining how bilingual international graduate assistants in science fields engage their undergraduate students to construct discipline-specific meanings through the chronotopic (re)contextualization of their prior physics reasoning and future applications in present discussions about physics events. This study also explores how competing interactions between undergraduate physics students in international graduate assistant-led learning contexts create spaces for peer language socialization. In addition, this study uncovers the tensions experienced by international graduate assistants concerning the institutionalized ideological forms of knowledge construction within a physics community.

This dissertation study is drawn from a larger, multi-site ethnographic language socialization project. Data examined for the study included 98 hours of video-recordings of classroom socialization activities between international graduate assistants and their U.S. undergraduate students in three undergraduate-level physics classes. Findings illustrate the *simultaneous* chronotopes of physics discursive practices engaged student participation and maintained the *sequential* chronotope in international graduate assistant-led socialization activities, demonstrating a joint attention between instructors and students as co-contributors to meaning making. The chronotopic link creates a dialogic space in which multidiscursive practices of knowledge construction were achieved through the integration of disciplinary spatial repertoires and mathematical symbolism and images. Findings also highlight the heteroglossic nature of physics discourse practices and demonstrate how tension in competing notions of how to construct disciplinary expertise were resolved through 'carnival play' (Bakhtin, 1981) which mitigated student mathematics anxiety. The competing discourses of expertise between undergraduates created spaces for peer language socialization which might momentarily decenter the international graduate assistants' position as physics instructors but opened the floor to a number of legitimate ways of constructing expertise in a physics community. The present dissertation study suggests a spatial repertoire-informed chronotopic turn in analyzing the dynamic multiplicity of physics discourse practices and socialization activities in academic contexts (Lai, 2020).

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Chapter 1

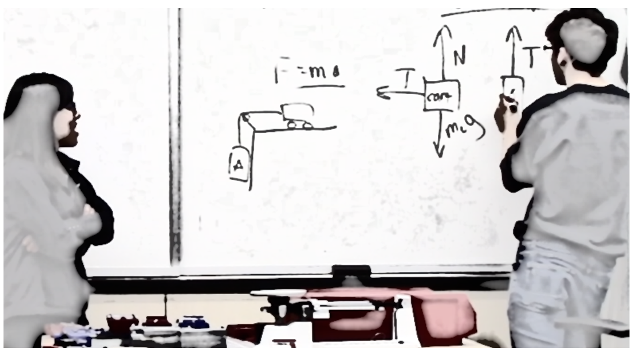
Language socialization in physics discipline

1.1 Meaning making through spatial repertoires and mathematical symbolic systems

Physics is a science discipline concerned with nature and properties of matter and motion through space and time, and the related entities of energy and force. Physicists understand their discipline to be a logical reasoning and spatial process concerning abstract physics facts, concepts, and theories. They navigate and deploy multiple resources in the construction of meaning, including (1) verbal and/or written utterances, embodied communicative practices such as hand gestures; (2) multimodal materials or artifacts, such as textbooks, laboratory notebooks, white/blackboard, diagrams, graphs, laboratory equipment and tools; and (3) mathematical symbolic systems, such as physics notations (e.g., Greek letter ω, omega, refers to angular velocity), and mathematical equations (e.g., Newton's Law of Motion $f = ma$). Through these meaning systems, discoveries and implications can be made to advance our understanding of the physical world. In this dissertation, I apply the term 'spatial repertoires' (Canagarajah, 2017, 2018) to refer to the interactivity of embodied linguistic-multimodal repertoires used as an assemblage in meaning making in physics discourse practices.

In most scientific communication and interaction, verbal and written texts would make no sense without integrated mathematical equations and visual representations that may not be effectively paraphrased in natural language (Lemke, 1998). The visual displays of a physics event under discussions, such as free-body diagrams that graphically illustrate Newton's Laws of Motion, provide physicists with a cognitive and spatial domain to conceptualize physics facts concerning forces and directions acting on mass objects. For instance, Figure 1 exemplifies how free-body diagrams assist one of my international graduate assistant participants, Kelly[1], and her undergraduate physics student Alex to visualize different kinds of forces (e.g., tension, gravity, natural force) and their directions acting on two mass objects tied by a string.

Figure 1: Free-body diagrams that visually demonstrate forces and their directions acting on mass objects [Kelly's classroom, October 11, 2017]



The visual representations in Figure 1 "transport physics phenomena into the perceptual presence of physicists and also serve as a locus in which physicists and physics phenomena can be brought into physics and symbolic contact with one another" (Ochs et al., 1996, p. 350). Physicists frequently return to visual displays in scientific communication as a way of (re)grounding prior physics reasoning and future applications in present discussions about a physics event. For instance, Figures 2 and 3 exemplify the simultaneous use of visual representations in instruction where Kelly teaches the algorithmic procedure to solve a Newton's Laws of Motion question. Firstly, Kelly points to Newton's Second Law of Motion ($F = ma$) on the board (see Figure 2). She then verbally explains that the physics relation between acceleration (a) and tension (T) acting

[1] Pseudonyms have been assigned to all the international graduate instructors who participated in the present dissertation project as focal participants and undergraduate physics students as non-focal participants.

on the object (i.e. the *cart* in Figure 1) are equal. This physics relation is symbolically indexed through the mathematical equation $T = m_c a$ (tension force equals mass of the cart times acceleration) (see Figure 3).

Figure 2: Instruction about the directions of acceleration and tension through simultaneous use of pointing gestures and visual representations [Kelly's classroom, October 11, 2017]

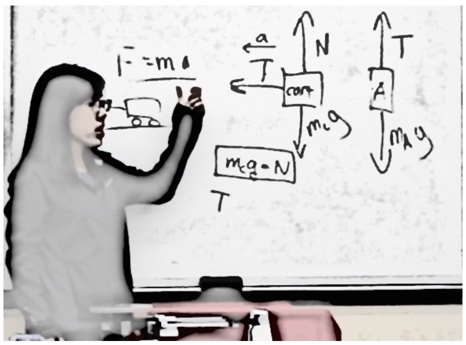
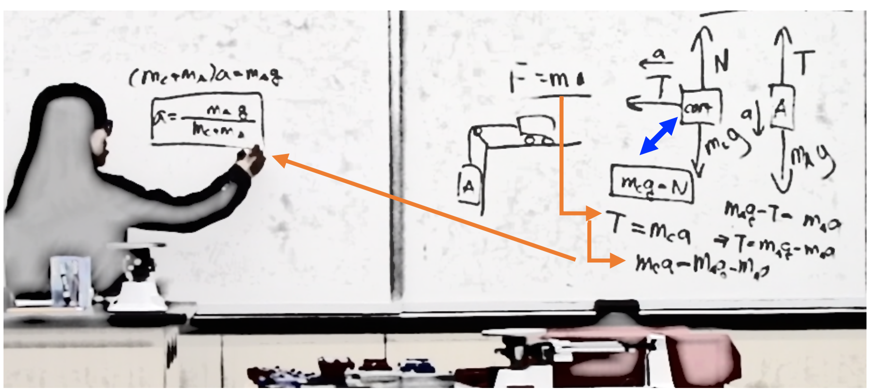


Figure 3: Physics relations between the mass and acceleration acting on the object cart and object A demonstrated through mathematical equations [Kelly's classroom, October 11, 2017]



Following this mathematical reasoning and the spatial process between the visual representations and mathematical equations, Kelly writes another mathematical equation, $m_c a = m_A g - m_A a$, to indicate the physics relations between the mass and acceleration acting on the cart and object A (see Figure 3). Because the acceleration acting on the cart and object A are equal, Kelly writes another equation $(m_c + m_A)a = m_A g$ to obtain the acceleration $a = \frac{m_A g}{(m_c + m_A)}$ and solve the physics question (see Figure 3).

1.2 Gap remaining in the literature

U.S. higher education has employed increasing numbers of bi/multilingual international students as international graduate assistants teaching graduate-level or undergraduate-level courses[2]. This is especially critical in the fields of science, technology, engineering, and mathematics (STEM). While international student employment is a considerable professional benefit for international students and their host institutions, it can pose a significant challenge for institutions to prepare their international graduate assistants to meet the learning needs of undergraduate STEM students, and for the international graduate assistants to define their roles as experienced experts and competent instructors in their instructional practices.

Scholars from diverse disciplines have continued to study the communication and interaction challenges that international graduate assistants encounter in their instructional activities with undergraduate STEM students. One such discipline is applied linguistics. Linguists with anthropological perspectives have documented the internal and external socialization resources deployed by international graduate assistants to advance their disciplinary knowledge, legitimize their academic identity, and become members of their community of practice (e.g., Anderson, 2017; Bhalla, 2019). Additional work, which used a micro-analytical method informed by a discourse analysis approach or an

[2] In this dissertation project, the term— international graduate assistants— is used to refer to international graduate students at a U.S. university who are pursuing advanced degrees and who are also employed by their host universities to teach and conduct research. Another common term used to refer to this population is ‘international teaching assistants.’

interactional sociolinguistic perspective, has identified not only the grammatical but also pragmatic functions of sentence completion (e.g., Chiang, 2011, 2016), discourse markers (e.g., Looney, 2015), and intonation (e.g., Lindemann, 2002; Pickering, 2019) in international graduate assistant-led instructional activities. These studies have provided insightful perspectives for understanding what might lead to instructional challenges facing international graduate assistants and undergraduate students. Yet, these lines of research need to further acknowledge and consider how disciplinary meanings in sciences are built and situated within scientific communication through the integration of linguistic and non-linguistic resources, multimodalities, and mathematical symbolic systems. These works also need to further address how specific disciplinary discursive practices shape the STEM instructional interaction between international graduate assistants and undergraduate students.

To address the gaps remaining in the literature on international graduate assistant-led socialization activities, this dissertation uses a language socialization approach and multimodal conversation analysis method to examine how situated discursive practices mediate international graduate assistant-led socialization activities and instructional communication within the physics discipline. This project also explores the ways international graduate assistants draw on their spatial repertoires and mathematics knowledge to construct and negotiate academic expertise in interaction in relation to the physics discipline.

1.3 How linguistic anthropologist approaches physics socialization activities

Language socialization is an interdisciplinary field of research examining the interconnected processes of language acquisition and socialization in diverse contexts

(Ochs & Schieffelin, 2012). In higher education contexts, language socialization scholars continue to study how situated discourse practices mediate socialization activities and processes, and how linguistically-culturally-diverse members draw on their communicative repertoires to develop their disciplinary expertise and habitus (Bourdieu, 1991). According to Bourdieu, habitus refers to a set of dispositions that incline individuals to interpret the social and physical world around them and respond to it in certain ways. Habitus generates perceptions, embodied practices, and attitudes that are normal to a cultural group without being consciously coordinated by any rules. Habitus can be acquired through primary and secondary socialization into the world through language, family, culture, and the milieu of educational or professional contexts.

Within the physics discipline, meaning making in socialization activities, mediating through the discursive features of language, mathematical symbolic systems, and multimodalities, is significant to temporality and spatiality. Physicists frequently (re)contextualize both the prior texts and future applications in order to understand the new meanings that become salient in the present communication while the old meanings still exist in the background (Ochs, Jacoby, & Gonzales, 1994; Ochs, Gonzales, & Jacoby, 1996). Applying Bakhtin's (1981, 1986) dialogic construct of intertextuality[3], the discourse features of physics socialization activities can be conceived as 'text' or 'discursive' practices in a given physics event. How are the intertextual features of physics discourse practices related to one another? What roles do these intertextual features play in meaning making in physics socialization activities? The present

[3] The word 'intertextuality' does not appear in Bakhtin's writings. The concept of 'intertextuality' was coined and introduced by Kristeva ([1966]1974) in her doctoral dissertation where she developed her theory of inter-textuality based on Bakhtin's construct of dialogism.

dissertation study aims to examine this area of inquiry which motivates the analysis in Chapter 4.

To answer the questions stated above, I follow Bakhtin's dialogic construct of intertextuality and consider that the textual or discursive practices of physics socialization activities are in constant dialogue with each other— that is, through their intertextual readings, physicists interpret and explain utterances, texts, mathematical equations, and/or multimodalities that are connected to the specific physics activity that is being discussed at the current moment. The mediating order of physics discourse practices resides in the intertextual network (Bakhtin, 1986) which is established through the (re)contextualization of academic language in physics, communicative multimodalities, and mathematical symbolic systems. The (re)contextualization is a process through which a text or utterance is extracted from its original context and inserted into a new one. As a text or utterance enters a new context, new meanings are situationally signified (Linell, 1998). Considering the dialogic features of physics discursive practices, I use the term 'spatial repertoires' (Canagarajah, 2017, 2018) to refer to the verbal and non-verbal features of physics discursive practices as a set of heteroglossic linguistic repertoire, gestures, body movements, material objects, environment, and multimodal semiotic resources that work as an assemblage in a spatially situated academic activity.

The physics socialization interlinks three temporal activities: prior logical reasoning; future responses; and present on-going involvements (Lai, 2020). The three temporal activities can take place across a variety of spaces: bodily (e.g. transition between hand gestures and head nodding), multimodally (e.g. transition between verbal lecture and graphic representations on board), or mathematically— that is, the relations between mathematical participants (e.g., Greek letter θ, meaning an unknown angle in trigonometry) and physics quantities (e.g., physics notation omega ω, meaning angular velocity) in the mathematical equation being used. The intertextual nature of physics discursive practices evokes Bakhtin's (1981) dialogic concept of 'chronotope' (literally time-space)— the meeting place of literary and artistic visualization across time and space, or the permeable boundary between text and experience, author and animator, which is mediated through socialization processes and practices. Bakhtin was inspired by Albert Einstein's Theory of Relativity, borrowed Albert Einstein's concept of time-space, and used it as a metaphor in his analysis of literature genres. Bakhtin suggested that time and space are actually inseparable in texts or discourses, and that this unit constitutes the chronotope of the self and other individuals, the self and groups, and the self and contexts (Holquist, 2010).

The present dissertation uses Bakhtin's (1981) concept of chronotope to examine how disciplinary knowledge is constructed between international graduate assistants and undergraduate physics students through the chronotopic (re)contextualization of their prior physics reasoning and future applications in present discussions about a physics event. This chronotopic (re)contextualization process requires a physicist's interpretive journey through the following discursive features: the integration of discipline-situated spatial repertoires (i.e. academic language in physics, multimodalities) and mathematical symbolism and images (e.g., Newton's Second Law of Motion equation $F = ma$). The *time* structure (i.e. the interplay between prior physics reasoning and future responses in current on-going involvements) and *space* structure (i.e. places where different modes of discursive practices are demonstrated sequentially or simultaneously, physically or bodily) are what I term the *chronotope* of physics discourses. This project asserts that an analysis of the chronotopic nature of diverse spatial repertoires is essential to understanding the dynamic multiplicity of physics discourse and instructional practices by international graduate assistants.

Theoretically and analytically, it is critical to recognize the multiplicity of disciplinary-situated ideological genres of discourses and the diversity of individual voices (Todorov, 1981, p. 56). Bakhtin's (1981) definition of 'heteroglossia' is thus employed here to denote the dimensions of multidiscursivity that are inherent to any forms of physics discourse practices between multilingual international graduate assistants and U.S. undergraduate students. All of the focal international graduate assistant participants in the present dissertation study are bilingual speakers— that is, though their first language may not be English language, they have been learning and researching their areas of expertise in more than one language and are pursuing their Ph.D. degrees through the medium of the English language. During some international graduate assistant-led instructional activities and U.S. undergraduate-initiated questions, international graduate assistants and undergraduate students paused in conversation due to different discursive registers between their primary physics education. To move the socialization activities forward, how do international graduate assistants and undergraduate students engage with those communication and interaction challenges? How does the heteroglossic nature of physics discourse practices create dialogic spaces for both international graduate assistants and undergraduates to negotiate meaning and establish mutual understanding? This is another area of inquiry that the present dissertation study aims to explore and that motivates the analyses in Chapters 4 and 5.

1.4 Design and purpose of the study

The dialogic nature of physics discourse practices underlines the integration of disciplinary spatial repertoires and mathematical symbolic systems in physics socialization activities. This dialogic nature not only reflects the synchronic juxtaposition of discursive practices related to different teaching-learning spaces in the classroom, but also reflects a diachronic dimension in which present on-going involvements link back to prior logical reasoning and forward to future applications. Bringing together language socialization theory, a joint method of multimodal conversation analysis, and Bakhtin's (1981) dialogic concepts of chronotope and heteroglossia, the present dissertation project fills gaps in the literature by examining: (1) how the chronotopic features of physics discursive practices can be related to one another and can shape the disciplinary contexts of physics, and how this chronotopic nature shapes meaning making in physics socialization activity; (2) how international graduate assistants and U.S. undergraduate physics students engage with communication and interaction challenges in order to move the socialization activities forward, and how this heteroglossic nature of physics discourse practices creates dialogic spaces for both international graduate assistants and U.S. undergraduates to negotiate meaning and construct mutual understanding; and (3) what the institutionalized instructional practices are, and how those practices can shape the socialization activities led by international graduate assistants. These objectives generate critical insights into current research on academic discourse processes and practices and move beyond a theoretical understanding to a grounded examination of language socialization in science disciplines.

The present dissertation project pays close attention to the moment-by-moment unfolding of disciplinary spatial repertoires and mathematical symbolic systems in interaction, examining particularly the socialization activities through which international graduate assistants socialize U.S. undergraduate students to become competent members of the physics community who understand how spatial repertoires, mathematics knowledge, and physics contexts connect to each other (Garret, 2017). The dual focus on the mediation resources and institutional contexts allows me to maintain a commitment to linking local-level socialization practices and broader structures of disciplinary (re)production and cultural transformation (Douglas Fir Group, 2016; Garrett & Baquedano-López, 2002). This dissertation study addresses the following Research Question 1 that centralizes the dialogic nature of discourse and instructional practices for an examination of interaction, participation structures, and ideologies situated in socialization activities within science disciplines:

1. What is the dialogic nature of language socialization in physics context between bi/multilingual international graduate instructors and undergraduate students?

    (a.) How can meanings be constructed through spatial repertoires and mathematical symbolic system, chronotopically, in physics socialization interaction?

    (b.) What challenges do bi/multilingual international graduate instructors encounter in their instructional interactions with undergraduate students? How do instructors and students engage with those challenges?

This dissertation study is drawn from a larger, 16-month ethnographic language socialization research project at a U.S. Midwestern state university. For the whole research project, ethnographic data were collected across three field sites at this U.S. Midwestern state university: (1) Field Site 1: one graduate-level University Teaching

Practicum program designed for its international graduate assistants across diverse academic disciplines at this Midwestern state university. In Field Site 1, classroom observation fieldnotes were taken in order to become familiar with the institutionalized instructional responsibilities and expectations that international graduate assistants need to undertake; (2) Field Site 2: one graduate-level College of Science and Engineering (CSE) Practicum program designed specifically for the CSE international graduate assistants at this Midwestern state university. In Field Site 2, ethnographic data (e.g., classroom observation fieldnotes, video and audio recordings of classroom socialization activities, interviews) were collected in order to become familiar with the institutionalized classroom communicative practices and cultural expectations that international graduate assistants were socialized into by the program faculty; and (3) Field Site 3: three undergraduate-level *Introductory Physics for Science and Engineering* classes taught by three of my focal international graduate assistant participants. In Field Site 3, ethnographic data (e.g., classroom observation fieldnotes, video and audio recordings of classroom socialization activities, interviews) were collected to answer the Research Question 1 that guided this dissertation study, which explores the dialogic nature of physics discourse and socialization activities between bi/multilingual international graduate assistants and U.S. undergraduate physics students.

The classroom discourse data collected in Field Site 3— that is, the socialization activities between CSE international graduate assistants and their undergraduate physics students— were transcribed using a multimodal conversation analysis (Lai, in progress) that combines methods of conversation analysis (e.g., Mondada, 2018; Schegloff, 2007) and multimodal discourse study of mathematics (O'Halloran, 2015). The transcribed data were analyzed using this multimodal conversation analysis and Bakhtin's (1981) concepts of chronotope (literally, time-space) and heteroglossia (particularly, its significance to indexicality, tension, and multivoicedness). The joint analytical methods are central to my dissertation project in order to: (1) emphasize the dialogic nature of discourse practices and institutional ideologies that are inherent in socialization activities; and (2) address how broader institutional and sociopolitical ideologies are or are not demonstrated, accommodated, resisted, and transformed in local-level socialization routines of everyday life.

1.5 Outline of chapters

I organize this dissertation into seven chapters. Following the introduction chapter, Chapter 2 provides an overview of the three strands of research that are most pertinent to the present dissertation study, including language socialization; discourse study of science/mathematics communication and interactions; and Bakhtin's dialogism of chronotope and heteroglossia. I also explain how the three strands support and dialogue with one another to lay the groundwork for the present dissertation project that studies the dynamic multiplicity of physics socialization activities and discourse practices in academic contexts. Chapter 3 explores the methodological approaches that guide this dissertation study and address the research questions introduced in the present chapter. This chapter also details the ethnographic data collected in Field Site 3 in 2017-2018. In addition, I explain the analytic methods used for data transcription and data analysis of physics socialization activities that are mediated through the integration of disciplinary spatial repertoires and mathematical symbolic systems.

Chapter 4 answers the Research Question 1 by examining the chronotopic nature of physics discourse practices and instructional activities between bi/multilingual international graduate assistants and their U.S. undergraduate physics students. This chapter also addresses the sub question 1(a) considering how meaning making in physics socialization activities is mediated through disciplinary spatial repertoires and mathematic symbolic systems in a chronotopic manner. In this chapter, I apply Bakhtin's (1981) construct of 'chronotope' to examine how disciplinary knowledge is constructed between international graduate assistants and U.S. undergraduate physics students through the chronotopic (re)contextualization of their prior physics reasoning and future applications in present discussions about a physics event.

Chapter 5 answers the sub question 1(b) through an examination of the challenges related to disciplinary discourse and ideological practices that bi/multilingual international graduate assistants encountered in their socialization activities with U.S. undergraduate physics students. This chapter also addresses how both the focal international graduate assistant participants and their undergraduate students engaged with those challenges to facilitate the socialization processes in physics contexts. In this chapter, I apply Bakhtin's (1981) concept of 'heteroglossia' to explore how increased competing discourses of expertise between undergraduate physics students in international graduate assistant-led learning contexts create spaces for peer language socialization, and between the focal international graduate assistant participants and institutionalized ideological forms of knowledge construction within physics community.

To conclude, Chapter 6 looks back on the findings and incorporates them into a discussion of the dialogic (chronotopic, heteroglossic) nature of physics discourse practices, considering its implications to meaning making, interactional sequence, and institutionalized ideologies in language socialization in academic contexts. I then go on to consider linguistic anthropology and multimodal conversation analysis as complementary perspectives in the study of discourse practices in science communication and interactions.

Chapter 2

Theorizing physics discourses through language socialization and Bakhtin's dialogism

Bringing together language socialization theory, a joint method of multimodal conversation analysis, and Bakhtin's (1981) dialogic construct of chronotope and heteroglossia, the present dissertation project examines: (1) how institutionalized ideologies shape the instructional practices and socialization activities between international graduate assistants and their undergraduate physics students; (2) how the chronotopic features of physics discursive practices are related to the disciplinary contexts of physics, and how these features shape meaning making in physics socialization activity; and (3) how the heteroglossic nature of physics discourse practices creates dialogic spaces for both international graduate assistants and their undergraduate students to negotiate meanings, construct mutual understanding, and compete for disciplinary expertise.

While I situate my dissertation within the field of language socialization (e.g., Duranti, Ochs, & Schieffelin, 2012), this work is an interdisciplinary project and draws from research across studies of science/mathematics communication and interactions (e.g., Lemke, 1998; O'Halloran, 2015; Roth, 2002) and of Bakhtin's (1981, 1986) construct of chronotope and heteroglossia. At the heart of each of these fields are *socialization activities, discourse practices, or spatiotemporal expressions that are mediated through the interactivity of linguistic-physical-multimodal material resources*. Without such mediation links, the socialization process of becoming a competent member becomes challenging.

In Chapter Two, I provide an overview of the three strands of research that are most pertinent to the present dissertation study: language socialization; discourse study of science/mathematics communication and interactions; and Bakhtin's dialogism of chronotope and heteroglossia. I characterize the primary concerns of each strand and illustrate their relevance to my project by providing scholarly discussions that are representative of the fields and that delineate gaps remaining in the literature. Furthermore, I explain how the three strands support and dialogue with one another to lay the groundwork for the present dissertation project that study the dynamic multiplicity of physics socialization activities and discourse practices in academic contexts.

2.1 Language socialization: Theoretical foundations

Language socialization— an interdisciplinary field of research rooted in anthropology, applied linguistics, and sociocultural theories— studies the interconnected processes of language acquisition and socialization (Duranti, Ochs, & Schieffelin, 2012). Within the language socialization discipline, language learning is a lifelong process that involves both developing proficiency in the grammar of a linguistic code and becoming competent in the social norms for communication in a cultural context. The theoretical and methodological commitment of language socialization rests neither on less experienced individuals as knowledge recipients nor on more experienced members as knowledge providers. Language socialization centers the socioculturally organized interactions in which both less and more experienced individuals socialize themselves and are socialized by each other, in and through the use of language, to use the language and engage in socially situated practices.

2.1.1 Socialization mediated through language and multimodal resources

Language socialization refers to the process by which children or newcomers in a culture group develop and practice "tacit knowledge of principles of social order and systems of belief through exposure to and participation in language-mediated interactions" (Schieffelin & Ochs, 1986, p. 2). 'Language' is fundamental to this concept because language is seen as "a great force of socialization, probably the greatest that exists" (Sapir, 1933, p. 15), and "a powerful semiotic tool for evoking social and moral sentiments, collective, and personal identities tied to place and situation, and bodies of knowledge and belief" (Ochs & Schieffelin, 2008, p.8). Each cultural group has available to its members the linguistic and multimodal repertoires which encode social actions and epistemic stances that are linked to the group membership identities and activities[4] (Ochs, 2004; Ochs & Schieffelin, 1984, 2009). In the present dissertation, I use the term 'spatial repertoires' (Canagarajah, 2017, 2018) to refer to the interactivity of embodied linguistic-multimodal repertoires employed as an assemblage in meaning construction in physics discourse practices. An examination of the socializing affordances is essential to understanding the discursive structures of physics communication and socialization activities that are mediated through spatial repertoires and mathematical symbolic systems.

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[4] As defined by Ochs (2004), *social action* refers to "a socially recognized goal-directed behavior," such as asking for clarification, making a request, catching a ball; *epistemic stance* denotes "a person's knowledge or belief, including resources of knowledge and degrees of commitment to truth and propositions"; the contextual dimension of *social identity* involves "a range of social personae, including, for example, social roles, statues, relationships, [and memberships]"; *social activity* refers to "at least two coordinated and situated actions and/or stance displays by one or a group of people" (p. 108-109). For example, a microteaching practice in the teaching practicum program for international graduate assistants is an activity that offers international graduate assistants repeated opportunities to learn and practice a variety of linguistic structures and expressions for clear, effective delivery of disciplinary knowledge.

‘Interaction’ is also crucial to the foundation of language socialization because participation in linguistically-multimodally mediated and socioculturally situated interactions is key to the acquisition of habitus[5] (Bourdieu, 1989) that is explicitly defined and implicitly indexed through the use of language and multimodalities (Ochs, 2004). This ‘interaction’ focus highlights the theoretical and methodological requirements for understanding that the ways in which international graduate assistants ‘learn how to teach’ (de León, 2012) depend on local theories of knowledge construction, demonstration of agency, and participation structures for interaction in a culture group. Linguistically and multimodally-mediated activity is thus the primary unit of analysis and indicator of language and cultural competence development.

In a variety of participant roles (e.g., speaker, addressee, overhearer, audience) (Goodwin & Goodwin, 2004), more experienced members often scaffold less experienced participants’ language development and sociocultural competence by continuously positioning less experienced members as observers and overhearers of recurrent communicative activities, orienting them to pay attention to the participation framework in conversation (e.g., conversation turns), and prompting them to repeat utterances to other interlocutors (Ochs, 1988; Schieffelin, 1990). Indeed, many socialization activities involve asymmetric knowledge and power that position more

[5] According to Bourdieu (1991), habitus refers to a set of dispositions that incline individuals to interpret the social and physical world around them and respond to it in certain ways. Habitus generates perceptions, embodied practices, and attitudes that are normal to a cultural group without being consciously coordinated by any rules. Habitus is acquired through primary and secondary socialization into the world through language, family, culture, and the milieu of educational or professional contexts. One key points within Bourdieu’s theory is that habitus constraints but does not determines an individual’s agency. Bourdieu outlines four species of capital that are linked to habitus— social, cultural, economic, and symbolic capitals— as they are parts of the structuring process of habitus and used by individuals as tools for constructing and negotiating dominance and power within relative social and physical spaces.

experienced members as experts and newcomers as apprentices (Goodwin & Kyratzis, 2012). Local theories of teaching and learning are often characterized by repetitive learning of language use (e.g., modeling, imitation, rehearsal, and performance) that entails a particular hierarchical relationship between more and less experienced members (Moore, 2006). However, the reverse is also common. For example, in a practicum program designed for international graduate assistants, it is not merely the graduate assistants who are being socialized to become competent instructors; the graduate assistants, through their verbal participation in class discussions, are also socializing the program professors to become more aware of the cross-linguistic, intercultural communication challenges facing international graduate assistants. Likewise, in a physics socialization activity between international graduate assistants and their undergraduate physics students, it is not only the undergraduates who are being socialized to become a member of the physics community; the undergraduates, through their verbalizations and non-verbal actions, are also socializing their graduate assistants to become course instructors.

The concept of agency has profound implications for the dynamic interactional foundation of language socialization in academic contexts. Agency refers to "the socioculturally mediated capacity to act" and "all action is socioculturally mediated, both in its production and in its interpretation" (Ahearn, 2001, p. 112). Ahearn applied a practice theoretical perspective of meaning constraint to more fully define the dialogic construction of meaning and agency:

> In advocating a practice theory rather than a theory of reception, however, I emphasize how individuals, including scholars, actively construct and constrain– rather than passively receive– interpretations that are both socially mediated and intertextually situated within a bounded universe of discourse. (p. 112)

Agency is not merely an individual's demonstration of free will. A central concern in taking agency as a synonym for free will is that this approach "ignores or merely gives lip service to the social nature of agency and the pervasive influence of culture on human intentions, beliefs, and actions" (Ahearn, 2001, p. 114). Moreover, agency is also not resistance in interaction. Treating agency as a synonym for resistance has the potential to lead to a "romance of resistance" (Abu-Lughod, 1990), minimizing the constraining power of structures and norms (e.g., linguistic, economic, sociopolitical in nature), and resulting in a more deductive view of agency and language practices. For many linguistic anthropology scholars, pure free will or resistance does not exist because the exercise of agency is complicated and contradictory, reflecting and simultaneously being shaped by multiple sociolinguistic scales (Ahearn, 2001).

Fairclough (2007) also highlights that social agents are not free agents. Social agents are socially constrained, but their actions are not totally socially determined because "agents have their own 'casual powers' which are not reducible to the casual powers of social structures and practices" (p. 22). Agency is mediated through not only larger sociopolitical structures and ideologies but also linguistic and semiotic meanings co-constructed in discourse in action (Agha, 2004; Duranti, 2004; Scollon & Scollon, 2003). As Giddens (1979) indicates,

> The active role of the child/novice in generating social order is compatible with social theories that promote members' reflexivity, agency, and contingency in the constitution of everyday social life (Bourdieu, 1977; Garfinkel, 1967). These approaches favor the study of social actions as at once structured and structuring in time and space, bound by historically durable social orders or power and symbolic system yet creative, variable, responsive to situational exigencies and capable of producing novel consequences. Even in the maintenance of social

> regularities, “the familiar is created and recreated through human agency itself”. (p. 128)

One approach to the tension outlined here is to take agency as multiple agentive acts that involve accommodation to, or reinforcement of, one’s positions in relation to others in discourse in interaction (Al Zidjaly, 2009; Kulick & Schieffelin, 2006). Individuals actively construct and constraint rather than passively receive knowledge provided to them. Less experienced members are not merely recipients of knowledge, but rather “active contributors to meaning and outcome of interactions” with other members of a cultural group (Schieffelin & Ochs, 1986, p. 165). Moreover, the meaning making construction in interaction is socially mediated and intertextually situated within a bound of larger discourses (Ahearn, 2001). Agency in creativity and critical thinking is crucial in the formation of discourse habitus and the transformation of heart and mind (Moore, 2006). Applying this concept to further explore the dynamics of physics socialization activity by international graduate assistants, I question the pre-deterministic dichotomy between more and less experienced members in interaction. Although some factors such as levels of familiarity with U.S. classroom interaction cultures may constrain their roles as graduate instructors, international graduate assistants exert their agency as physics experts to make choices to facilitate their socialization experiences in the practicum program, as well as their instructional practices with undergraduate physics students in the classes that they teach. When making choices, international graduate assistants also challenge certain institutional ideologies acquired in the process of becoming graduate instructors.

As Ochs and Schieffelin (2012) suggest: "language socialization is best viewed as an interactional rather than unidirectional process… all parties to socializing practices are agents in the formation of competence" (p. 5). The interactional perspective emphasizes that language and culture acquisition is a collaborative and dynamic process in that newcomers take active and selective social and communicative roles to co-construct knowledge and discourse conventions with other participants (Mehan, 1979). Acquisition of linguistic repertoire is not a simple reflection of what they learn from their sociolinguistic environment; instead, they are taking an active role in constructing language and social knowledge that is most useful to their needs and appropriate to their social roles (Schieffelin & Ochs, 1986). The interactional roles between less and more experienced members should be seen as contextual, relative, and negotiable positionalities rather than fixed assigned social categories (Lee & Bucholtz, 2015).

2.1.2 Becoming a speaker of culture

As newcomers become fluent and independent language users, they also gradually become recognized members of particular cultural groups. Language socialization is rooted in the foundation that the process of acquiring a language is part of a larger process of becoming a person in society (Schieffelin & Ochs, 1986), or 'becoming a speaker of culture' (Ochs, 2004). The process of becoming a speaker of culture entails understandings of social contexts and accommodations to the target cultural group's ideologies about linguistic and multimodal resources— that is, how these resources are used to acquire and display knowledge, express epistemic stance or emotions, perform social actions, constitute *self* and *person* identities (Davies & Harré, 1990; Harré & Moghaddam, 2003), and construct and negotiate memberships (Ochs & Schieffelin, 2012). These *id*eologies— *identity* and *ideas* that shape and are shaped by the contextual use of language and multimodal systems as well as the participation framework in interaction— can be explicitly defined or implicitly indexed through language learning and language use (Ochs, 1996; Ochs & Schieffelin, 2008). These *id*eologies denote “the culture system of ideas about social and linguistic relationships, together with their loading of moral and political interests” (Irvine, 1989, p. 255). In the process of developing one’s own disciplinary voice, language ideologies function as “the mediating link between social structures and forms of talk” (Woolard & Schieffelin, 1994, p.5), which influence sociopolitical attitudes and beliefs about newcomers as well as the language and cultural practices that members are expected to follow. For most international graduate assistants, the process of becoming a graduate instructor involves ideological struggles with disciplinary and institutional epistemologies. The concept of language ideologies allows a more detailed examination of how international graduate assistants in the physics discipline negotiate and resist certain idealized, institutionalized instructional practices (e.g., initiation-response-feedback).

Socialization processes of becoming a speaker of culture are situated locally in practices of communities[6] (Schieffelin & Ochs, 1986). Language socialization research

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[6] The concept of “practices of communities” (Schieffelin & Ochs, 1986) is distinct from that of “community of practice” (Lave & Wenger, 1991). These two concepts overlap and are interrelated with each other, but they are not synonyms. Both concepts consider the process by which participants in a community become more competent and recognized members as their participation increases and is closer to the target norms. However, as Baquedano-López and Kattan (2007) argued, the concept of “practices of communities” understands communities as social aggregates that can be studied by an analysis of their participants’ everyday language and cultural activities. The “communities” in this concept is not necessarily defined by shared participants’ practices. By contrast, the construct of “community of practice” defines communities through their participants’ professional activities and shared practices (e.g., conference presentations as academic and scientific performances).

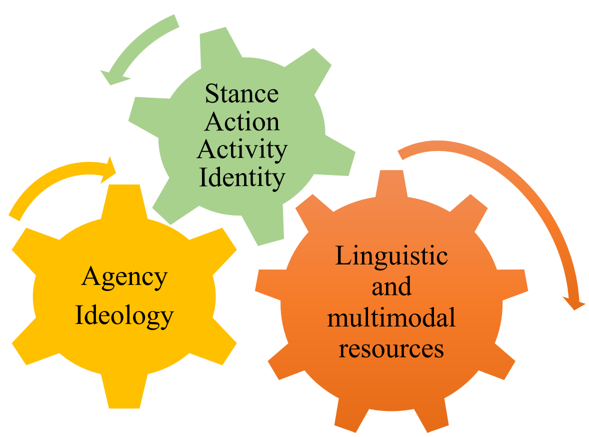
has advanced the concept that the acquisition of language and communicative competence is not a neutral and value-free process. Knowledge is never neutral and is always embedded within social-historical-political-ideological contexts mediated by different forms of oppression (e.g., Gramsci's internalized hegemony, as discussed in Ives, 2004) and of power (e.g., that are shaped by cultural, ideological, linguistic, material, physical, or psychological) (Carspecken, 1996). Among different forms of oppression and power, language is central to the formation of subjectivities (both conscious and unconscious awareness) and subjugations (Blommaert, 2005; Wodak, 2011). Language is not a neutral and objective conduit of description of the social world but serves as a force of regulation and domination. The tension between the local theories of knowledge and language and the more globally mediated culture symbols creates fluid views of disciplinary communities and multilingual and multimodal practices across academic fields (Arnaut, Blommaert, Rampton, & Spotti, 2015; Blommaert, 2010). These viewpoints challenge current discussion concerning the (re)contextualized process of meaning making in physics socialization activities because physics communication is fundamentally dialogic and multimodal. Such complex understandings of practices of communities highlight how interactions reconcile macro-level sociopolitical ideologies with micro-level interactional negotiations of community memberships and identity.

2.1.3 Language socialization in academic contexts as situated practice and dynamic process

It is relatively recent that language socialization research has been recognized for its scholarly contributions to the process of language development and cultural learning in academic disciplines in higher education contexts. This line of research situates disciplinary language and cultural competence development "in the holistic contexts of everyday life" (Bronson & Watson-Gegeo, 2008, p. 43-44), exploring how individuals learn, experience, and use language and multimodal resources in a variety of academic contexts to reach discipline-specific sociohistorical, cultural, political, and linguistic interests. Language socialization into academic disciplines is a complex and conflictual process of negotiation rather than a predictable and one-directional process of enculturation (Duff, 2012). Discipline-specific linguistic and cultural practices are mediated through local theories and *id*eologies shared by group members and "complex networks of informal and formal social institutions that regiment, or attempt to regiment, cultural and symbolic values associated with different linguistic varieties and discursive expressions" (Duranti, Ochs, & Schieffelin, 2012, p. 485). Academic discourse refers to forms of oral and written languages and communication— grammatical structures, registers, genres, semiotic representations, interactional patterns— that are ritualized, expected, and evaluated by more experienced members in a discipline-specific community. Within the physics discipline, academic discourse practices can be displayed in texts, interactions, and discipline-specific contexts that involve linguistic, sociocultural, institutional, and historical foundations and functions.

Competent participation in a specific academic discourse community requires the ability to understand how language and multimodal semiotic resources are used to acquire or teach discipline-specific knowledge, perform actions, display epistemic stances with a variety of linguistic and semiotic resources and in a culturally appropriate manner, construct academic identities, and engage in academic activities (Ochs, 2004). Figure 4 below exhibits how one's knowledge and identity construction are mediated through linguistic-multimodal-repertoires and shaped by his/her agency and ideology. Members are exposed to these interdependent dimensions of academic context not in isolation but in concert as they are drawn into the life of a particular community of practice (Garrett, 2017). Within physics contexts, disciplinary activities (e.g., error analysis of the data collected from physics experiments) establish an academic medium for both international graduate assistants and their undergraduate students with repeated opportunities to practice their science knowledge and develop their identities as graduate instructors and undergraduate students of physics community.

Figure 4: Knowledge and identity construction mediated through linguistic and multimodal resources and shaped by agency and ideology



2.2 Discourse features of science communication and socialization

Within the contexts of science, linguists with anthropological perspectives have recognized that meanings are built through routine interpretive activities including talk, gesture, and visual representation among English-speaking physicists (e.g., Ochs, Jacoby, & Gonzales, 1994; Ochs, Gonzales, & Jacoby, 1996). Physicists grammatically express their subjective involvements by foregrounding their roles as practitioners (physicist as agent or as experiencer) of a scientific activity. Physicists also demonstrate their subjective involvements by taking the perspectives of a scientific activity being analyzed, and by involving themselves in visual representations of that specific activity[7].

Ochs and her fellow researchers (1994, 1996) have identified three common types of grammatical structures used by physics to construct their subjective and intersubjective involvements: (1) physicist-centered grammar (i.e. personal pronouns + predicates), in which physicists refer to themselves as agents or experiencers of a given physics event; (2) physics-centered grammar of scientific phenomena, through which physicists make no explicit reference to themselves as physicists, and foreground inanimate physics entities as the thematic focus and grammatical subject of the sentences. In such discursive practices, the physics entities are assigned two related semantic roles through predicates referring to either a motion change of state (e.g., *since it has constant angular velocity*) or a cognitive experience (e.g., *so the external force acting on the cart is tension*); and (3) indeterminate referent grammar (i.e. animate personal pronouns + inanimate physics event predicates), which blurs the separateness and distinction between physicists and the objects of physics inquiry. The personal pronouns are not restricted to either the speaker or addressee but can refer to referents that participate in present discussions about a physics activity. The verbs are usually simple present or present progressive, referring to the discussed physics activities under discussion as continuing rather than specific and punctual.

[7] A physics event means a scientific *thing*/*activity* that physicists discuss. For example, when physicists study the physics event of Free Fall, they examine the motion of an object where gravity is the main acceleration acting upon it, and where gravitation is reduced to a space-time curvature (e.g., initial velocity with respect to time and to height), a body in free fall has no force acting on it.

The indeterminate referent grammar can be semantically illogical and blurs the boundaries between the animate subject (physicist) and the inanimate object (physics event, entity, or system). However, this grammatical structure "displace[s] physicists into constructed worlds of physics events, they [physicists] do so as part of embodied interpretive practices" (Ochs, Gonzales, & Jacoby, 1996, p. 350). In other words, when physicists use indeterminate constructions, they can symbolically (re)position themselves in an imagined realm of physics events. The indeterminate referent grammar draws physicists into an intersection of multiple worlds, including the world of there-and-then versus here-and-now interaction (space-time), the world of graphic space, and the world of physics events symbolically represented by visual representations (Ochs, Jacoby, & Gonzales, 1994). Visual representations can "referentially constitute physicists and physics entities as simultaneous, co-existing participants in [physics] events" (Ochs, Gonzales, & Jacoby, 1996, p. 359). Such referential ambiguity (indeterminant referent grammar) allows physicists to symbolically (re)position themselves in physics events from the perspective of physics entities in multiple worlds that no physicists can experience.

Furthermore, Ochs and her fellow colleagues (1994, 1996) have also highlighted the importance of the interpretation of visual representations in science communication and socialization activities. Visual displays of a physics event provide physicists with a cognitive and spatial domain to conceptualize and "transport physics phenomena into the perceptual presence of physicists and also serve as a locus in which physicists and physics phenomena can be brought into physical and symbolic contact with one another" (Ochs, Gonzales, & Jacoby, 1996, p. 350). Physicists frequently return to visual demonstrations in interaction as a way to (re)ground prior physics reasoning and future applications in present discussions about a physics activity.

2.2.1 Gap remaining in the literature

The majority of language socialization research in higher education has predominantly focused on the role of language within the contexts of second/foreign/heritage language acquisition and performance. However, language is not the only medium for knowledge construction and meaning negotiation for scientists/physicists in socialization activities. Multimodal resources— such as visual representations of a scientific concept, gesture and body movements, sensory integration–– also complement the linguistic forms and functions in discourse in action as scientists/physicists advance their disciplinary competence and legitimize their academic identity in their specific areas of study (e.g., Alibali et al., 2014; Gerofsky, 2011; Jakonen, 2015; Lemke, 1998; Roth, 2000). Knowledge construction in sciences can differ across cultures and be shaped by the material resources and environments surrounding individuals (Barad, 2007). Applied linguist Canagarajah (2018) applies a spatial orientation informed by theories in material and spatial sciences to approach language competence and performance among bi/multilingual international STEM scholars. He underscores the integration of multilingual and polysemiotic practices of spatial repertoires for disciplinary expertise development by bi/multilingual international graduate assistants.

Other disciplines also acknowledge that words are not in isolation from multimodal resources in constructing knowledge and meanings. In the field of neuroscience, visual representations accelerate scientific inquiry and experimental analyses, as well as enable translation of mental images into discourse (linguistic and textual) practices (Uttal & O'Doherty, 2008). Visual displays also function as interactional cues for linguistic resources of spatial repertoires (Kosslyn, Ganis, & Thompson, 2001) and as epistemic support to scientific reasoning and spatial process with mental images (Svahn & Bowden, 2019).

Although language socialization research (e.g., Ochs et al., 1994, 1996) and applied linguistics work (e.g., Canagarajah, 2017, 2018) have highlighted the interactivity of embodied linguistic-physical-material resources used as an assemblage in meanings making in science communication and interactions, these lines of work need to further consider how disciplinary meanings are constructed *in situ* and situated within scientific communication through spatial repertoires and *mathematical symbolic systems*, and how specific disciplinary discursive practices shape the instructional interaction between bi/multilingual international graduate assistants and their undergraduate students. Furthermore, an analytical approach that accounts for the integration of spatial repertoires and mathematical symbolic systems is essential to examining the dynamic multiplicity of physics discourse practices and socialization activities. One such approach is multimodal discourse study of science/mathematics communication and interactions, in which language is considered as one source (usually a secondary one) that operates in conjunction with multimodal resources of spatial repertoires and mathematical symbolic systems to construct meanings in physics socialization activity.

2.2.2 A multimodal approach to mathematics and science discourse practices

Discourse analysts have applied a multimodal (i.e. multisemiotic) approach to the study of science/mathematics communication and interactions in school contexts. This multimodal approach leads to the concept of a multimodal register for mathematics and science discourse practices; meanwhile it also complements the existing language-based conceptualization of academic discourse practices. In this regard, the complexity and multiplicity of science/mathematics discourses locates itself in a larger scientific theoretical framework, wherein the grammatical metaphorical nature of reasoning is situated in the technical taxonomies[8] defined in science disciplines, rather than individual taxonomies themselves (Doran, 2018; Halliday, 1978, 1998; Lemke, 2003; O'Halloran, 2008, 2015). The grammatical metaphor of scientific reasoning can lead to semantic ambiguity and discontinuities in scientific discourses (Ginsberg, 2015; Lemke, 1990). The semantic ambiguity and discontinuities complicate the positioning of physicists as agents and physics as participants or vice versa, which can lead to indeterminant referent grammar in scientific reasoning (Ochs, Jacoby, & Gonzales, 1994; Ochs, Gonzales, & Jacoby, 1996).

Meaning making in physics socialization activities requires the integration of typological principles of linguistic semantics, quantitative mathematics (mathematical symbolism and equations), and topological modalities of visual semiotics (visual displays of a physics concept). Topological modalities of visual semiotics provide contextual information for scientific reasoning about the symbolic formulations of physics/mathematic entities and relations (e.g., points, lines, two-dimensional planes, three-dimensional objects) (Lemke, 1998). The use of symbolic conventions in mathematical graphs and diagrams (e.g., x, y, and z axes) are codified visually and

[8] According to Halliday (1993), technical taxonomies are scientific concepts that are classified based on underlying principles. For example, a 'sphere' is a non-polyhedral type of solid and a perfectly round geometrical object in three-dimensional space. All points on the surface of a sphere are the same distance r from its center. A sphere has no edges or vertices.

spatially in scientific ways. Visual representations yield “perceptual accounts of mathematical participants and their relations (e.g., in terms of similarity, proximity in space and time)” permitting insights in the nature of the physical realities encoded symbolically (O’Halloran, 2015, p. 70). Mathematical symbolic notations are designed semiotic resources that are different from human languages, representing an arbitrary liaison between a symbol or a symbolic expression (signifier) and a precise semantic meaning (signified) in physics socialization activities. A set of contextualized semiotic signs is used by physicists to signal, index, and interpret “what the activity is, how semantic content is to be understood and how each sentence relates to what precedes or follows” (Gumperz, 1982, p. 131). Context is socioculturally constituted, interactively sustained, and bounded by time (Goodwin & Duranti, 1992) and by space (Bakhtin, 1981; Ochs et al., 1994; 1996). Such semiotic signs are “habitually used and perceived but rarely consciously noted and almost never talked about directly. Therefore, they must be studied in context rather than in the abstract” (Gumperz, 1982, p. 131).

According to French linguist Saussure, a sign is composed of the signifier (signifiant, a sound-image or a written mark) and the signified (signifié, a concept). Saussure conceptualized the sign process as a static arbitrary defined relationship of signifier to signified. However, this conceptualization was challenged by the field of anthropology (e.g., semiotic anthropology) which drew on the tradition extending from Peirce (1885,1902) and Jakobson (1971) to re-conceptualize the linkage between signs and the sociocultural contexts of their use as mutually constitutive and analytical inseparable. Anthropologists applied a semiotic theory to consider the sign process as more than merely a sign’s indexing its object or action. Peirce proposed a third component, *interpretant*, which describes the result(s) of a sign's being indicated to its object or action (Mertz, 2007). Silverstein (1976, 2003) extended Peirce's work and defined the sign process— a sign pointing to or indexing an object or action in the context where it occurs— as indexicality or contextually bounded meaning. Applying the Peircean concept, for example, a yellow traffic light can be viewed as an image (a sign) whose object is a warning that a red light is soon to follow, and whose interpretant may be an individual's decision to slow down and get ready to stop his/her vehicle before the light turns red. In this framework, a potential representamen of the surrounding is viewed to extend beyond linguistic features (Enfield, 2011). The observed representamen can be contextually interpreted as meaningful even in the absence of an agentive speaker (Ahearn, 2001). This dissociation of meaning from the speaker's intent leads to an analysis of semiosis as a process of contextualization and interpretation, in which a sign can be seen as any perceptible feature, object, pattern, or event that is contextualized as meaningful by participants. Within physics socialization activities, the meaning of a Greek letter (e.g., ω) or a mathematical equation ($F = ma$) become visible when all interpretants of that sign (i.e. that specific Greek letter or mathematical equation) become relative correspondingly, and when all interpreters respond similarly to that sign.

Peirce (1885, 1902) further defined three different mechanisms through which a sign can be linked to its object or action— icon, index, and symbol. An icon indicates its object through shared physics qualities between signifier and signified, such as a portrait of Albert Einstein. An index refers to its object through which a signifier has a direct correlation in space and time with the signified, such as the Mass-energy equivalence indexes one of Einstein's contributions to physics. A symbol indicates its objects through arbitrary relation between signifier and signified, such as $E = mc^2$. A sign gains its meaning(s) through social convention. In the Peircean framework, a sign can blur the boundaries between icon, index, and symbol. A portrait of Einstein can be an icon that looks like its object Albert Einstein as well as an index that connects to the Mass-energy equivalence. As for symbols, $E = mc^2$, must be learned as indexes through the physics quantity represented by each symbol (i.e. symbols E stands for energy, m refers to mass, and c stands for speed of light). In physics, the Mass-energy equivalence states that an object having mass has an equivalent amount of energy and vice versa, with these physics quantities directly related to one another in Albert Einstein's formula $E = mc^2$. Here, physics symbols E, m, and c are not letters but physics notations that indexically suggest a disciplinary meaning. This typology demonstrates that, far from being arbitrary between signifier and signified, the meaning(s) of a sign is grounded in the participants' socialization experiences of the world through relations of iconicity and indexicality (Lemke, 1990; Ochs et al., 1994, 1996).

Within physics socialization activities, contextualized semiotic signs are mobile signifiers and signified located within the spatiotemporal links (Bakhtin, 1981). The ways signs gain meanings and interact with each other in a grammatical structure are explained by the processes of indexicality. Indexicality thus is a spatiotemporal process (Agha, 2004) as signs participate with other semiotic assemblages to construct meanings. For example, a demonstrative determiner such as *this* or *that* can refer to a specific physics event or scientific process in the world by being paired with a symbolic sign such as a physics symbol (e.g., omega ω means angular frequency) indexed by pointing gestures. The critical issue of physics reasoning is not the individual mathematical symbolic notation, but rather a systematic way in which the notations are organized to create meanings and develop argumentation reasoning. In this respect, I contend that the systematic methods of organizing mathematic symbolic notations and equations are part of the socialization process of becoming recognized members in physics in using appropriate contextualization cues.

In the present dissertation study, the multimodal analysis of discursive features of physics socialization activities illuminates how bi/multilingual international graduate assistants and their undergraduate physics students navigate and employ spatial repertoires and mathematical symbolic systems to simultaneously and/or sequentially (re)contextualize their prior physics/mathematical reasoning and future applications in present activities about a physics event. Furthermore, as I noted in Chapter One, meaning making in physics socialization activities, mediating through the confluence of spatial repertoires and mathematical symbolic systems, is significant to temporality and spatiality. This spatiotemporal nature of physics discourse practices evokes Bakhtin's (1981) dialogic concepts of 'chronotope' (literally time-space) and heteroglossia. In the next section, I provide a discussion of the theoretical foundation of Bakhtin's chronotope and heteroglossia, along with how these concepts inform my analyses of the dynamic multiplicity of physics socialization activities between bi/multilingual international graduate assistants and their undergraduate physics students in academic contexts.

2.3 Dialogism of chronotope and heteroglossia of physics socialization activities

Meaning making in physics discourse practices resides in the intertextual network (Bakhtin, 1986), which is established through the (re)contextualization of disciplinary spatial repertoires (i.e. academic language in physics, multimodalities) and mathematical symbolism and images. (Re)contextualization is a process through which a text or utterance is extracted from its original context and inserted into a new one. As these texts or utterances enter a new context, new meanings are situationally signified. The textual features of physics discourse practices are in constant dialogue with each other— that is, through their intertextual readings, physicists connect prior texts, mathematical equations, and multimodal materials to the new meanings that become salient in the specific physics activity that is being discussed at the present moment. According to Kristeva ([1966] 1974), intertextuality refers to the process in which meaning making is mediated through the signs that are available to readers from texts, rather than transferred directly from writers to readers. Within physics socialization activities, physicists interpret both prior texts and new ones in order to understand the new meanings that become salient while the old meanings still exist in the background. For instance, during some error analysis activities, international graduate assistants and their undergraduate students pause in discussion due to different discursive registers between their primary physics education. In order to move the socialization activities forward, graduate assistants or undergraduate students use classroom materials for physics experiments (e.g., mass sets, pulleys, strings) to visually demonstrate their understandings of the tension forces and their directions caused by the strings. The multimodal materials help supplement and complement the linguistic features of physics communication. The multimodal materials also help link the linguistic descriptions of a given physics activity to the associated physics quantities (e.g., tension t, mass m, gravity g) and to the mathematical equations that are symbolically represented by physics/mathematics symbols (e.g., $t = mg$).

2.3.1 Chronotopic nature of socialization activities

This dialogic intertextual nature of physics discursive practices evokes Bakhtin's (1981) construct of 'chronotope' (literally time-space)— the meeting place of literary and artistic visualization across time and space, or the permeable boundary between text and experience, author and animator, which is mediated through socialization practices. Bakhtin explained his concept of 'chronotope':

> We will give the name chronotope (literally, "time space") to the intrinsic connectedness of temporal and spatial relationships that are artistically expressed in literature. This term [space-time] is employed in mathematics and was introduced as part of Einstein's Theory of Relativity. The special meaning it has in relativity theory is not important for our purposes; we are borrowing it for literary criticism almost as a metaphor (almost, but not entirely). What counts for us is the fact that it expresses the inseparability of space and time (time as the fourth dimension of space) … In the literary artistic chronotope, spatial and temporal indicators are fused into one carefully thought-out, concrete whole. Time, as it were, thickness, takes on flesh, becomes artistically visible; likewise, space becomes charged and responsive to the movements of time, plot and history. This intersection of axes and fusion of indicators characterizes the artistic chronotope. (p. 84)
>
> The chronotope in literature has an intrinsic generic significance. It can even be said that it is precisely the chronotope that defines genre and generic distinctions, for in literature the primary category in the chronotope is time. The chronotope as a formally constitutive category determines to a significant degree the image of man in literature as well. The image of man is always intrinsically chronotopic. (p. 85)

Bakhtin borrowed the time-space concept from Albert Einstein's Theory of Relativity and applied it as a metaphor to his analysis of literature genres. In his work, Bakhtin identified "the literary artistic chronotope" where the "spatial and temporal indicators are fused into one carefully thought-out, concrete whole. Time…becomes artistically visible; likewise, space becomes charged and responsive to the movements of time…This intersection of axes and fusion of indicators characterizes the artistic chronotope" (p. 84). Applying the Bakhtinian view of chronotope to the instance and figures above, the *time*/*chrono* of meaning making in physics discourses becomes visible through the organization of mathematical reasoning (e.g., from equations $f = ma$ to $T = m_c a$). The *space*/*tope* of meaning making in physics, including the international graduate assistants' pointing gesture and visual displays of forces and their directions acting on objects, simultaneously becomes responsive to the sequence of mathematical reasoning. In the present study, the analysis of chronotopes illuminates how international graduate assistants navigate and employ disciplinary spatial repertoires and mathematical symbolic systems to simultaneously and/or sequentially (re)contextualize their prior mathematical reasoning and future applications in the specific physics activity that is being discussed at the current moment.

Wertsch (1992) defined Bakhtin's chronotope as either *sequential* conversations including code transfers for communication purposes between individuals or *simultaneous* communication containing multiple, conflicting perspectives between participants or languages. In Wertsch's viewpoint, chronotopes of physics instructional practices can be *sequential*, moment-by-moment, turn-by-turn unfolding of interactions involving negotiation of meanings or *simultaneous* conversations including competing, overlapping voices between international graduate assistants and their undergraduate students.

Furthermore, Bakhtin's (1981) chronotope emphasizes the spatiotemporal link mediated through the indexicality of semiotic signs for the realization and instruction of artistic thoughts (Morris, 1994). Within the physics discipline, indexicality is a spatial process (Agha, 2004) in which spatial repertoires participate with mathematical symbolic systems to construct meanings. For instance, a demonstrative determiner such as *this* or *that* can refer to a specific physics event or scientific process in the world by being paired with a symbolic sign such as a physics notation (e.g., omega ω means angular velocity) indexed by pointing gestures. As Bakhtin (1981) noted,

> "in order to enter our experience (which is social experience) they must take on the form of a sign that is audible and visible for us (a hieroglyph, a mathematical formula)… Without such temporal-spatial expression, even abstract thought is impossible. Consequently, every entry into the sphere of meanings is accomplished only through the gates of the chronotope" (p. 258).

A sign that is audible and visible to international graduate assistants and undergraduate physics students for meaning making includes: (1) disciplinary spatial repertoires, which include a set of linguistic (multilingual) competence, communicative multimodalities (e.g., gesture or body movements), material objects, and physical environments that collaboratively work as an assemblage in a spatially situated activity (Canagarajah, 2017, 2018; Lemke, 2005) and (2) mathematical symbolic systems, which include mathematical equations, images, and physics notations (Lemke, 1998; O'Halloran, 2015). Meaning making in physics socialization activities can be a space of ideological struggles for international graduate assistants and U.S. undergraduate students because the construction of subjective and intersubjective involvements is not merely linguistic performance of disciplinary knowledge. Intersubjectivity refers to mutual understandings around a common activity during socialization (Duranti, 1997). When assessing a scientific event being discussed in interaction, physicists take up a subjective stance that simultaneously involves their positionings in relation to others. Subjectivity-taking acts are dialogic in nature, aligning the interlocutors turn-by-turn, moment-by-moment in interaction and creating intersubjectivity between them (Ochs & Schieffelin, 2012; Schegloff, 1992). In the present dissertation project, an analysis of chronotopes provides a nuanced insight into the sequential and spatial nature of repertoires that serve as collective assemblages through which international graduate assistants and their undergraduate students construct intersubjective knowledge in a chronotopic manner.

2.3.2 Heteroglossic nature of socialization activities

Considering the fluidity of disciplinary discourse practices between bi/multilingual international graduate assistants and U.S. undergraduate students, the present dissertation study applies Bakhtin's (1981) construct of 'heteroglossia' to frame the various academic registers that both graduate assistants and their undergraduates employ to construct disciplinary knowledge and expertise in classroom interaction for specific spatially situated academic activities. In the Bakhtinian view, heteroglossia is defined as the dynamic multiplicity of discursive practices and the varieties of voices as legitimate members of a given discourse or cultural group. Heteroglossia sees language in use or discourse in action as ideologically saturated and stratified because:

> [Language or discourse] represents the co-existence of socio-ideological constructions between the present and past, between differing epochs of the past, between different socio-ideological groups in the present, between tendencies, schools and so forth, all given a bodily form. (Bakhtin, 1981, p. 291)

Within the physics discipline, the heteroglossic nature of physics discourse practices indexes "specific points of view on the world, forms of conceptualizing the world in words, specific world views, each characterized by its own objects, meanings and values" (Bakhtin, 1981, p. 291-292). Meaning making "belongs to a word in its position between speakers; that is meaning is realized only in the process of active, responsive, understanding" (Volosinov, 1986, p. 102-103). In the Bakhtinian sense, the construction of disciplinary expertise in physics socialization activities can thus be both personal and scientific, and intertwined with other members or with relevant physics concepts in constant dialogues.

Theoretically and analytically, it is critical to recognize the multiplicity of disciplinary-situated genres of discourses and the diversity of member voices (Todorov, 1981, p. 56). For Bakhtin, heteroglossia is significant to *indexicality*, *tension*, and *multivoicedness* (Blackledge & Creese, 2014; Busch, 2014). Indexicality is a process of a sign pointing to some object in a specific context where that sign gains meanings (Peirce, 1885, 1902). Both heteroglossia and *indexicality* reside in the intertextual network where "meanings of forms depend on past usages and associations of those forms rather than on arbitrary referential meaning inherent in the form" (Bailey, 2012, p. 500). Within the physics discipline, indexicality can be seen as a spatial process (Agha, 2004) as academic registers in physics participate with mathematics and multimodalities to construct meanings. For instance, a demonstrative determiner such as *this* or *that* can refer to a specific physics event or scientific process in the world by being paired with a symbolic sign such as a physics symbol (e.g., omega ω means angular frequency) indexed by pointing gestures. Indexicality is also an ideological process, as indexical links between language or discourse practices and social meaning reside in sociocultural assumptions and norms. That is, particular language forms and uses become ideologically recognized as indexing certain social meanings and identities (Silverstein, 2003), such as science nerds (Braden, under review).

The heteroglossic nature of physics socialization activities is also characterized by the *tension* between the centripetal force of centralization and the centrifugal force of diversification. Bailey (2012) noted that what is significant about heteroglossia "is not its reference to different kinds of linguistic signs and forms, but rather its focus on social tensions inherent in language" (p. 508). That is, tension emerges between the centralizing centripetal force of power (which does not allow alternative approaches to meaning making) and in the de-centralizing, centrifugal force of power that accepts distinct voices (Blackledge & Creese, 2014). In the present dissertation study, this tension appears when the juxtaposition between disciplinary content experts and U.S. classroom discourse novices creates interactional consequences for international graduate assistants' instruction and their situated identities as graduate instructors vulnerable to the negotiation of their subject-area knowledge and expertise.

For Bakhtin (1981), all texts, languages, or discourse practices are inherently dialogic because those practices have "at the same time, a history and a present which exist in a continually negotiated state of intense and essential axiological interaction" (p. 279). In this regard, individuals do not simply speak but envoice (Bakhtin, 1986) or populate utterances with their own histories and expressive intentions (Bakhtin, 1981). From this perspective, every utterance is multivoiced, reflecting an explicit or implicit dialogue with other voices of the past, present, and future. Within the physics discipline, the multivoiced nature of heteroglossia provides a critical tool to more fully uncover the fluid, dynamic nature of the construction of disciplinary expertise among less and more experienced physicists.

Thus, the heteroglossic nature of physics socialization activities underlines the co-presence of indexicality, tension, and multivoicedness in the construction of disciplinary expertise and membership identity. The present dissertation project aims to provide a more nuanced insight into how bi/multilingual international graduate assistants' and U.S.

undergraduate students' existing heteroglossic voices and discourses shape their participation in physics socialization activities as relatively less or more experienced members. To this extent, the present dissertation project argues that the heteroglossic nature of physics socialization activities is a demonstration of physicists' disciplinary spatial repertoires related to given mathematics and physics concepts, as well as their human experiences and engagement in quantitative mathematics and natural sciences.

Chapter 3

Research methods: Critical ethnography and multimodal conversation analysis

The present language socialization project integrates ethnographic and multimodal conversation analysis methods to explore the institutional structures and cultural interpretations of discourse practices and disciplinary ideologies that inform participants' engagements in socialization activities within science disciplines. Chapter Three explores the methodological approaches that guide this dissertation study and address the Research Question 1 introduced in Chapter One. It begins with a brief description of what I observed in Field Sites 1 and 2 which informed the present study's design and led me to focus on the discourse practices and socialization activities between international graduate assistants and their undergraduate STEM students. I also offer an ethnographic account of Field Site 3 where the present study's fieldwork was conducted, as well as background information of my study participants in Field Site 3. In the second part of the chapter, I provide discussions on the methodological underpinnings of critical ethnography and how these foundations informed my study design, as well as a description of data collection and data sources.

In the third part of the chapter, I present analytical methods used for data transcription and data analysis. The classroom discourse data collected in Field Site 3— that is, the socialization activities between international graduate assistants and their undergraduate physics students— were transcribed and analyzed combining the method of multimodal conversation analysis with Bakhtin's (1981) concepts of chronotope (literally, time-space) and heteroglossia (specifically, indexicality, tension, and multivoicedness). The combined analytical methods are central to the present project in order to: (1) explore the dialogic nature of discourse practices and institutional ideologies that are inherent in socialization activities; and (2) address how broader institutional and sociopolitical ideologies are demonstrated in and shape the local-level socialization routines of everyday life.

The methods outlined in the chapter are used to identify the epistemological, disciplinary, and sociopolitical points of contention that shape my positionality (as a linguistic anthropologist, international graduate instructor, and non-scientist) and my ability to answer the research question. I aim for transparency throughout, and I show how an ethnographic method of data collection and data analysis combining the method of multimodal conversation analysis with Bakhtin's dialogism are the most appropriate approach to examine the dynamic multiplicity of physics discourse practices and socialization activities.

3.1 Field sites and study participants

In this section, I provide a brief description of what I observed in Field Sites 1 and 2 which informed this dissertation's study design and fieldwork. I also offer an ethnographic account of Field Site 3 where this study's fieldwork was conducted and provide background information of my study participants in Field Site 3. I strive to represent individuals and their activities which were situated in places/contexts that were recognizable to them. But I know, this lens is my own vision as an ethnographer (Heath & Street 2008). My project takes an ethnographic approach to document how socialization activities "taken collectively, not as isolated instances" mediate disciplinary instructional practices (Garrett, 2017, p. 284).

3.1.1 Field site 1: Graduate-level University Teaching Practicum class

My research interests in language socialization and situated discourse practices in academic contexts grew out of my long-term engagements with multilingual international (graduate) student populations at U.S. universities. The majority of the populations were Ph.D. students who worked as international graduate assistants in science disciplines. Based on the conversations with those future scientists, I was aware of some cultural differences between science and social science disciplines, such as the role of language plays in scientific communication and socialization activities (international graduate assistants' instructional practices that socialize U.S. undergraduate students into a scientific community of practice).

In order to become more familiar with the situated discourse and instructional practices of scientific communities, I enrolled in a semester-long, graduate-level University Teaching Practicum class for credits in Fall semester 2016. This graduate-level University Teaching Practicum class was taught by faculty members in the Center for Educational Innovation at a Midwestern state university. The class was designed for international graduate students across diverse disciplines at the Midwestern state university who are employed as graduate instructors. The Midwestern state university, where the present dissertation project took place, seeks to provide an inclusive learning and teaching environment for its linguistically and culturally diverse student and faculty populations. During the academic year of 2018-2019, this university recruited 2,992 graduate-level international students from around the world (around 24.36% of the total university student enrollment). Almost half of the international graduate student populations, or 1,258 graduate students, was enrolled in the College of Science and Engineering (CSE). One funding source offered by the CSE departments to support its international Ph.D. students is part-time employment as graduate assistants (with tuition reduction), teaching undergraduate-level laboratory and discussion classes.

The graduate-level University Teaching Practicum class was designed to fulfill the mandate of the Minnesota State Second Special Legislative Session of 1985 (Chapter 11, Section 7, Subdivision b) and the Midwestern state university policy (*English proficiency for nonnative English-speaking teaching assistants*). Both the State legislation and University policy aim to ensure that classroom teaching assistants whose primary language is not English develop high-level proficiency in English speaking, reading, and writing. The curriculum design for the graduate-level University Teaching Practicum class addressed pedagogical, cultural, and linguistic aspects of teaching with the goal that international graduate assistants can gain communication skills required to successfully undertake their instructional responsibilities in U.S. higher education classrooms.

As a participant-observer, I wrote classroom observation fieldnotes from Fall semester 2016 to Spring semester 2017. These fieldnotes provided me with an understanding of how the Practicum class faculty socialized their international graduate assistants into institutionalized instructional responsibilities and expectations. The Practicum class consisted of: (1) a weekly one-hour lecture that provided a forum to discuss topics associated with U.S. classroom routines of instruction (e.g., engaging undergraduate students through an Initiation-Response-Evaluation interactional pattern). International graduate assistants also reflected on the linguistic and cross-cultural challenges (e.g., undergraduate student behaviors) they might encounter in classrooms; and (2) a weekly one-hour language lab to provide micro-teaching practices for international graduate assistants to learn to articulate and speak comprehensibly to university undergraduate students in English using both technical and non-technical terms. Although the curriculum designed for the class was language-centered, the course syllabus stated that the goal of the class was not to train international graduate assistants to sound like native U.S./English speakers, but rather to be intelligible to the linguistically and culturally diverse undergraduates in the classes taught by international graduate assistants (see Figure 5).

Figure 5: Screenshot of the statements about language and culture assumptions on the course syllabus for the University Teaching Practicum class

> Finally, it is important to have realistic goals for language development. The goal is not to sound like a native U.S. speaker, but rather to be intelligible to students in the U of M classes you teach. In this course, you need to demonstrate sufficient proficiency to convey discipline-specific content effectively, as well as comprehend students' questions and comments. Minor language errors that do not interfere with meaning are expected. Of course, dialectal variation in native Englishes from around the world is also expected.

Moreover, and more importantly, the nature of knowledge construction varies across disciplines. As shown in Chapter 1, within the physics discipline (and other science fields), meaning making and negotiation are mediated through the integration of spatial repertoires and mathematical symbolic systems. Very often language is considered a secondary source that operates in conjunction with multimodal resources of spatial repertoires and mathematical symbolic systems to construct knowledge in physics (and other scientific) socialization activity. Is every instructional miscommunication a result of international graduate assistants' lack of English language proficiency? If meanings are constructed through constant dialogues between individuals or between individuals and material environments (Bakhtin, 1981; Goodwin, 2018; Schegloff, 1992), how can we not question whether instructional miscommunication is also a result of undergraduates' lack of content knowledge in sciences and/or mathematics? An analysis of the dialogic nature of physics discourse practices is essential to understanding the dynamic multiplicity of physics instructional interactions between international graduate assistants and their undergraduate students. I thus decided to continue my fieldwork observations in: (1) the College of Science and Engineering (CSE) Practicum program designed for CSE international graduate assistants, in order to become more familiar with how CSE international graduate assistants are socialized into the classroom discourse practices and cultural expectations related to STEM instruction in U.S. higher education and (2) the *Introductory Physics for Science and Engineering* classrooms taught by my focal international graduate assistant participants, in order to further study how physics discourse practices and instructional interactions are mediated through the confluence of spatial repertoires and mathematical symbolic systems.

3.1.2 Field site 2: CSE Practicum program for international graduate assistants

As mentioned in the previous section, the majority of the international graduate student populations at the Midwestern state university are enrolled in the College of Science and Engineering (CSE). One funding opportunity given by the CSE departments to support its international Ph.D. students is part-time employment as graduate assistants (with tuition reduction), teaching undergraduate-level laboratory and discussion classes. In order to meet the mandate of the Minnesota State Second Special Legislative Session of 1985 (Chapter 11, Section 7, Subdivision b) and the Midwestern state university policy (*English proficiency for nonnative English-speaking teaching assistants*), the CSE financially founded an intensive three-week, CSE Practicum program. This Practicum program was designed exclusively for first-year CSE international graduate assistants to become familiar with classroom communicative practices and cultural expectations related to STEM instruction in U.S. higher education. According to the Midwestern state university policy, all the first-year CSE international graduate assistants were required to score 27/30 or higher on the speaking portion of the TOEFL Internet Based Test. After meeting this university language proficiency requirement, all the first-year CSE international graduate assistants were required to attend and complete the CSE Practicum program before beginning their first-semester teaching. All the CSE international graduate assistants had previously studied their areas of research in both their first languages and English.

The CSE recruited a number of faculty members from the Center for Educational Innovation at the same university to design and teach in this discipline-specific program that addressed linguistic, cultural, and pedagogical aspects of instruction with the purpose that CSE international graduate assistants can develop the communicative competence required to successfully undertake their teaching responsibilities in CSE classrooms. None of the faculty members employed from the Center for Educational Innovation were CSE professors and scientists. They were experienced educators with an expertise in teaching English as a second language.

The CSE Practicum program consisted of a one-week online session followed by a two-week face-to-face session. During the one-week online session, lectures were given to the CSE international graduate assistants with a focus on U.S. campus life, U.S. classroom communicative practices between teachers and students, and cross-cultural expectations of teaching assistants. The CSE international graduate assistants participated in five online discussion activities in which they reflected upon cultural similarities and differences in instructor roles, student behaviors, and classroom environments between their own primary culture and the USA. The CSE international graduate assistants also self-identified their own pronunciation and grammar challenges related to their individual disciplinary discourse practices, video-recorded how they pronounced phrases or sentences, uploaded their recordings to the course website, and received feedback from the CSE Practicum program faculty.

During the two-week face-to-face session, in the daily morning section, the CSE international graduate assistants were engaged in the classroom activities that focused on the linguistic and cultural aspects of instruction (i.e. spoken English skills). These activities included pronunciation practices (e.g., targeting intonation and enunciation) and group discussions in which CSE international graduate assistants voiced their concerns about multicultural issues such as gender, race and ethnicity, politics and religion on U.S. campuses. A most common concern shared among CSE international graduate assistants was appropriate pragmatic use of language in interaction on sensitive topics, such as those related to sociopolitical ideologies (e.g., political orientation, international tensions).

In the daily afternoon section, the CSE international graduate assistants participated in the classroom activities that focused on the cultural and pedagogical aspects of instruction. The Practicum program faculty socialized the CSE international graduate assistants into U.S. classroom interaction routines, such as the I-R-E (initiation-response-evaluation) instructional sequence. Most of the time, the program faculty invited the graduate-level resource teaching assistants to exemplify how to initiate a question, encourage the class to answer, respond to students, and evaluate the student responses. The graduate-level resource teaching assistants were more experienced CSE international graduate assistants who had taught undergraduate-level CSE classes.

The program faculty and CSE international graduate assistants also worked together to analyze case examples that illustrated cultural differences and misconceptions for effective instruction. For instance, the CSE international graduate assistants were socialized into the reality that not every undergraduate CSE student would have had the same level of access to STEM instruction in their prior K-12 education. The CSE international graduate assistants thus should not assume that undergraduate CSE students would have the same level of STEM knowledge needed to follow the classroom instruction. To teach more challenging scientific concepts or mathematical equations, CSE international graduate assistants were advised to simplify and slow down their instruction or connect those concepts with lived examples or visual representations (see Figure 6). During instruction activities in which undergraduate CSE students failed to correctly answer questions, the CSE international graduate assistants were advised to correct undergraduates' answers in a positive manner in order to help alleviate student mathematics/science anxiety.

Figure 6 exemplifies the use of visual representations in teaching more challenging science and/or mathematics concepts by a graduate-level resource teaching assistant [Afternoon session, August 8, 2017]

Another main component of the afternoon section was micro-teaching practice. Based on their departments, the CSE international graduate assistants were divided into small groups and given a specific teaching topic each day. The topic of the day might include giving a lesson on conservation of momentum and energy, responding to student incorrect answers or logistical questions. Each CSE international graduate assistants then presented a 10-minute lesson to graduate-level resource teaching assistants from their own department. After this micro-teaching practice, the CSE international graduate assistants received comments and suggestions for improvement from the graduate-level resource teaching assistants.

Towards the end of the first and second week, each CSE international graduate assistants made a 10-minute teaching demonstration. For their teaching demonstrations, the CSE international graduate assistants self-selected a lesson topic from introductory courses in their individual departments designed for the first-year undergraduate students. They then developed a 10-minute lesson plan by applying the principles and strategies learned in the Practicum program. The CSE international graduate assistants' teaching demonstrations were evaluated by both the Program faculty and graduate-level resource teaching assistants. At the end of their 10-minute teaching demonstrations, the CSE international graduate assistants were asked to respond to diverse instructional situations, such as giving alternative explanations of more challenging mathematical concepts.

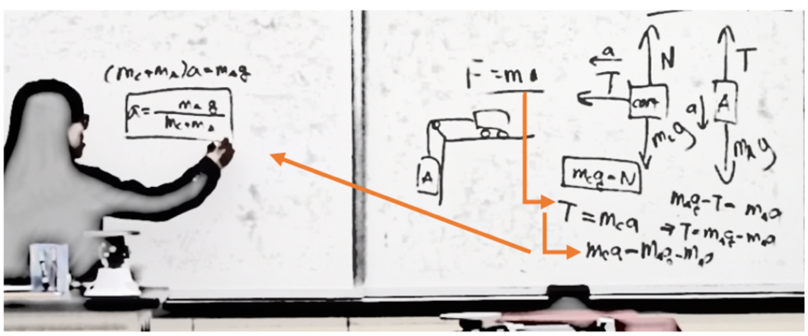
3.1.3 Field Site 3

***3.1.3.1 Introductory Physics for Science and Engineering* class**

The undergraduate-level *Introductory Physics for Science and Engineering* class is designed and offered by the School of Physics and Astronomy to undergraduate students enrolled in the College of Science and Engineering. In this required course, international graduate assistants socialized their undergraduate physics students into the physics reasoning processes through the use of fundamental principles in solving quantitative problems focused on motion, forces, conservation principles, and structure of matter. These physics international graduate assistants also taught their undergraduate students to how to apply those fundamental concepts to mechanical systems. The undergraduate physics students who were taking the *Introductory Physics for Science and Engineering* class were also required to concurrently take an advanced calculous class offered by the Department of Mathematics. The *Introductory Physics for Science and Engineering* class is an ideal space for researching the dialogic (chronotope, heteroglossia) nature of spatial repertoires that characterize physics instructional practices, interlinking the prior logical reasoning and future applications in the present discussion about physics events. The class also provides a rich context to explore the integration of disciplinary spatial repertoires and mathematic symbolic systems situated in physics socialization activities.

The *Introductory Physics for Science and Engineering* course was designed for undergraduate students to work closely with their physics international graduate assistants to conduct physical experiments, analyze data collected from experiments, and solve physics and mathematical problems in student homework assignments. The physics international graduate assistants explained to their undergraduate students how they as more experienced physicists read and interpreted the problems, and how physical concepts and mathematical equations were applied to solve those problems (see Figure 7). The Phycids international graduate assistants also reviewed the physical theories taught by the department professors in lecture sessions, answered any remaining questions the students might have, discussed with students to design their experiments examining the physical events learned in the lecture classes, and analyzed data (error analysis) collected from the experiments.

Figure 7 exemplifies the mathematical equations and images used by a physics international graduate assistant to teach the relations between the mass and acceleration acting on objects [Kelly's classroom, October 11, 2017]



Furthermore, in the *Introductory Physics for Science and Engineering* class, the physics international graduate assistants socialized their undergraduate students into academic discourse practices of writing a data analysis paper within the physics disciplines. They taught their undergraduate physics students how to apply physics and mathematics knowledge, such as mathematical equations and images, in experimental data analysis. This was part of the socialization process of becoming a legitimate member of the physics community at using their physics knowledge logically to theorize and analyze the data collected from the experiments.

3.1.3.2 Physics international graduate assistant participants

Three physics international graduate assistants— Gina, Kelly, and Ian (pseudonyms)— participated in my dissertation project as focal participants. I invited these three physics international graduate assistants to join my dissertation project because they were active participants in the CSE Practicum program activities. For instance, these three physics international graduate assistants often asked their Practicum program faculty for alternative communicative practices or strategies in instruction. I selected the classroom excerpts from these three focal participants' classes because of the rich interactive environments they created to engage their undergraduate physics students to draw on their spatial repertoires in meaning making in physics socialization activities.

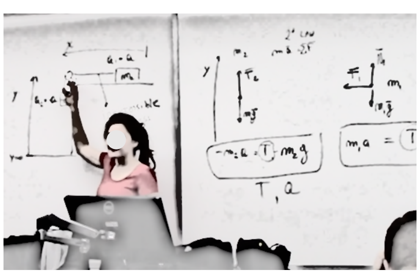
The three physics international graduate assistants— Gina, Kelly, and Ian— were first-year Ph.D. students in the School of Physics and Astronomy (see Table 1 and Figure 9). Gina is from Argentina and a bilingual speaker of Argentinian Spanish and English. Both Kelly and Ian are from Taiwan and bilingual speakers of Mandarin Chinese and English. They had previously studied their areas of expertise in both their first languages and English. Before coming to the Midwestern state university for their Ph.D. study in physics, all of them had had extended laboratory training in physics in their prior institutes in their home countries.

Gina's research work centers on theoretical physics and mathematics. She often told her undergraduate students that because mathematical competence is key to physics/science, students should train themselves like robots to apply mathematical equations in physics reasoning. Kelly is also interested in theoretical physics and mathematics. Kelly's undergraduates were always amazed at her mental mathematics skills in solving complicated physics problems that involved multiple mathematical equations and calculus. Ian's study interests include theoretical physics and astronomy. Ian always engaged his undergraduate students in physics reasoning by detailing the processes of mathematics reasoning or by visualizing abstract concepts with the use of experiment materials. All of the three physics international graduate assistant participants were appointed to teach laboratory classes in their prior institutions in their home countries. However, none of them had had prior teaching experience in U.S. higher education institutes.

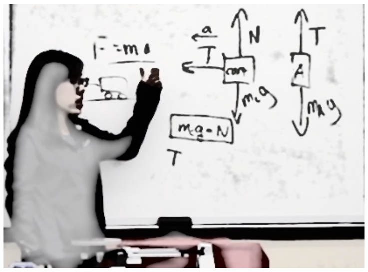
Table 1: Focal physics international graduate assistant participants

Name (pseudonyms)	**School**	**Year in program**	**Course taught**
Gina (Argentina, female)	Physics and Astronomy	1st	Introductory Physics for Science and Engineering
Kelly (Taiwan, female)	Physics and Astronomy	1st	Introductory Physics for Science and Engineering
Ian (Taiwan, male)	Physics and Astronomy	1st	Introductory Physics for Science and Engineering

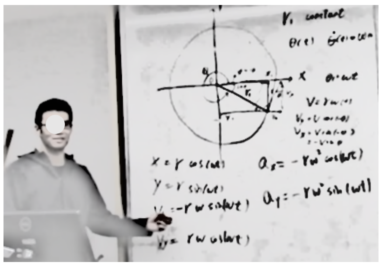
Figure 8: Images of Gina, Kelly, and Ian (from left to right)



Gina



Kelly



Ian

There were 20 first-year undergraduate CSE students enrolled in each of the three *Introductory Physics for Science and Engineering* courses that were taught by my focal physics international graduate assistant participants and where this dissertation project was conducted. These 60 undergraduate students were non-focal undergraduate student participants in the study and gave me permission to video record their classroom communication and interactions with their physics international graduate assistants and other classmates. Most of the non-focal undergraduate student participants were native English speakers while a few others were international undergraduate students.

3.2 Research design, data sources, and data collection

This dissertation study aims to examine the dialogic (chronotopic, heteroglossic) nature of discourse practices and institutional ideologies that are inherent in socialization activities. It also considers how broader institutional and sociopolitical ideologies are or are not demonstrated, accommodated, resisted, and transformed in local-level socialization routines of daily activities. As previously stated (p. 10-11), the following Research Question 1 guided the present study:

1. What is the dialogic nature of language socialization in physics context between bi/multilingual international graduate instructors and undergraduate students?

   (a.) How can meanings be constructed through spatial repertoires and mathematical symbolic system, chronotopically, in physics socialization interaction?

   (b.) What challenges do bi/multilingual international graduate instructors encounter in their instructional interactions with undergraduate students? How do instructors and students engage with those challenges?

This dissertation study aims to provide a more thorough understanding of the dynamic multiplicity of physics discourse practices and socialization activities led by international graduate assistants. The answers to the Research Question stated above have implications for further theoretical and methodological research around meaning making, interactional sequence, and institutionalized ideologies in language socialization in academic contexts.

3.2.1 Research design through a critical ethnographic method

This section provides discussions on the methodological underpinnings of critical ethnography and how these foundations informed my study design. It then offers a description of data collection and data sources. Critical ethnography[9] questions the

[9] Critical ethnography is a relatively recent development in social science research methodology. Situated within the broad ethnographic tradition, critical ethnography reflects several of the characteristics of ethnography. Watson-Gegeo (1988) defined ethnography as the "study of people's behavior in naturally occurring, ongoing settings, with a focus on the cultural interpretation of behavior… The ethnographer's goal is to provide a description and an interpretive-explanatory account of what people do in a setting (such as a classroom, neighborhood, or community), the outcome of their interactions, and the way they understand what they are doing (the meaning interactions have for them)" (p. 576). Critical ethnography follows a number of the core tenets of ethnographic approaches and methods, including: (1) a research focus on the study participants' communication habitus (Bourdieu, 1991); (2) a "thick description" (Geertz, 1994) and holistic and contextual interpretation of the study participants'

interpretive and naturalistic ethnographic work, which historically adopted a more detached, objective, and value-free orientation to knowledge construction (Anderson, 1989; Kincheloe & McLaren, 2000; Madison, 2012). This method sees the binary constructs in conventional ethnography—theory and method, subjectivity and objectivity, interpretation and description of data, and ethics and science—as interconnected, making mutual contributions to both epistemological and methodological knowledge (Carspecken, 1996; McLaren & Giarelli, 1995). Critical ethnography in the study of language socialization underscores the interconnected structures of disciplinary discourse practices and institutionalized ideologies by examining how such structures emerge from both the local-level socialization activities and societal-level ideological forces. These insights on ideological forms of disciplinary discourse practices challenge the pre-determined dichotomy of 'expert' and 'novice' members of a discourse community, complicating the relational roles of expert and novice as "contextual, relative, and negotiable positionalities rather than fixed culturally assigned categories" (Lee & Bucholtz, 2015, p. 323).

For critical ethnographers, doing ethnographic fieldwork is a personal experience because it is contextualized as a social practice composed of competing discourses—mediated by the ethnographer's embodiment in theory and methodology, positionality as a researcher and relationships with the study participants, and affective involvement in her project (McLaren, 1995). I seek a deeper immersion in my researched contexts to grasp what my study participants experience as meaningful in their daily routines of

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communicative and behavior patterns; (3) an "emic" analysis and abstract "etic" comparison[9] across languages, contexts, and cultures all derived from data collection (e.g., observation fieldnotes, collection of relevant documents) (Watson-Gegeo, 1988); and (4) an emergent and recursive relationship between theories, research questions, methods, and data (Talmy, 2011).

activities (Emerson, Fretz, & Shaw, 2011). As Goffman (1989) noted, ethnographic fieldwork involves:

> "subjecting yourself, your own body and your own personality, and your own social situation, to the set of contingencies that play upon a set of individuals, so that you can physically and ecologically penetrate their circle of response to their social situation, or their work situation, or their ethnic situation." (p. 125)

With immersion, I gain insights from the inside how my study participants socialize themselves and are socialized into discipline-situated discourse practices, and why and how they do this in this way (van Leeuwen, 2007).

When learning about my researched contexts and study participants through actively participating in their daily routines of activities, I understand that my ethnographic fieldwork should not attempt to be "a fly on the wall" (Emerson, Fretz, & Shaw, 2011, p. 4). Neither fieldwork nor ethnographer can be completely neutral, detached from the observed phenomenon. As Emerson and his colleagues highlighted, "the task of the ethnographer is not to determine 'the truth' but to reveal the multiple truths apparent in others' lives" (p. 4). Writing observation fieldnotes is not passively jotting down 'facts' about 'what happened;' rather, observation fieldnotes emphasizes some socialization patterns while ignoring and marginalizing others. Through participation, my study participants and I have developed "a nexus of shared practice and discourse that productively mediates differences between researchers' and [participants'] respective Discourses or habituses" (Jaffe, 2012, p. 350). Ethnographic fieldwork is not merely passive observation but rather interactive collaboration with the study participants. Through continuing participation, I collected first-hand fieldnotes contextualizing how meanings emerged through discourse-in-action and collective action among my study participants, how understandings and interpretation changed over time and across spaces, and how these changes shaped subsequent actions (Emerson, Fretz, & Shaw, 2011).

Critical ethnography recognizes that the researcher and the researched from a collaboration construction and are in constant dialogue (Madison, 2012). Building on constant dialogues with the researched, critical ethnographers not only become more fully themselves but also open themselves to know their researched contexts and study participants more fully. As Russian philosopher Bakhtin (1984) noted:

> "I am conscious of myself and become myself only while revealing myself for another, through another, and with the help of another. The most important acts constituting self-consciousness are determined by a relationship toward another consciousness (toward a thou) … To be means to be for another, through the other, for oneself" (p. 287).

Throughout the research design process, I considered vulnerability when self-reflecting on my researcher positionalities developed in dialogue with my study participants. I contextualized my researcher positionalities, "making it accessible, transparent, and vulnerable" (Madison, 2012, p. 9), to (re)examine potential unmarked privileges and ideologies that I might have before entering my research sites and interacting with my study participants.

Dialogue in critical ethnography also resists conclusions because it is committed to keeping open and ongoing the negotiations of meanings between and within both the researcher and the researched (Conquergood, 1985). Dialogue in critical ethnography is a reciprocal giving and receiving, rather than a one-time ethnographic *present* that projects "a timeless account of the culture or people being studied" (Madison, 2012, p. 11). Applying this concept in my dissertation, dialogue with my research participants for member checking and validation not only strengthen the trustworthiness of the study but also keeps the negotiations and conversations ongoing so that I see more fully their socialization into becoming a competent scientist and instructor in their individual disciplinary communities.

3.2.2 Data sources and data collection

Ethnographic data were collected in three field sites at the Midwestern state university, during a sixteen-month period in 2016-2018. Tables 2 details the fieldwork timeline and Table 3 shows data sources and data collection in each field site. Data sources analyzed for the present dissertation study included: (1) Observation fieldnotes across three Field Sites; (2) 96 hours of video recordings of the socialization activities in Field Site 3; (3) approximate 96 hours of transcribed video data of the socialization activities in Field Site 3; (4) analytic memos written throughout the data transcription and data reading processes; and (5) instruction materials and resources used by the focal physics international graduate assistant participants in Field site 3.

Table 2: Fieldwork Timeline

September 1, 2016 – May 5, 2017 (9 months)	**May 19– May 26, 2017** (1 week)	**August 7– August 21, 2017** (2 weeks)	**September 1, 2017 – January 31, 2018** (6 months)
Site 1: Graduate-level University Practicum class	**Site 2: CSE Practicum program for international graduate assistants (One-week online session)**	**Site 2: CSE Practicum program for international graduate assistants (Two-week face-to-face session)**	**Site 3: *Introductory Physics for Science and Engineering* class**
Data sources collected: • Classroom observation fieldnotes • Collection of relevant documents • Researcher reflexive account	**Data sources collected:** • Classroom observation fieldnotes • Collection of relevant documents • Researcher reflexive account **Non-Focal Participant:** • 1 faculty professor • 16 CSE international graduate assistants	**Data sources collected:** • Classroom observation fieldnotes • Video- and audio-recordings of classroom socialization activities, including micro-teaching practices • 1 Formal interview with Practicum program faculty and with graduate-level resource teaching assistant participants • Collection of relevant documents • Researcher reflexive account **Focal Participant:** • 1 faculty member • 1 Graduate-level resource teaching assistant **Non-Focal Participant:** • 16 CSE international graduate assistants	**Data sources collected:** • Classroom observation fieldnotes • Video- and audio-recordings of classroom socialization activities between focal Physics international graduate assistant participants and their undergraduate physics students • 2 Formal interviews with focal Physics international graduate assistant participants; the first interview conducted before the beginning of the semester and the second interview conducted after the end of the semester • Informal conversation with focal Physics international graduate assistant participants and their undergraduate physics students • Researcher reflexive account **Focal Participant:** • 3 Physics international graduate assistant participants **Non-Focal Participant:** • 60 undergraduate physics students who took the focal Physics international graduate assistant participants' classes

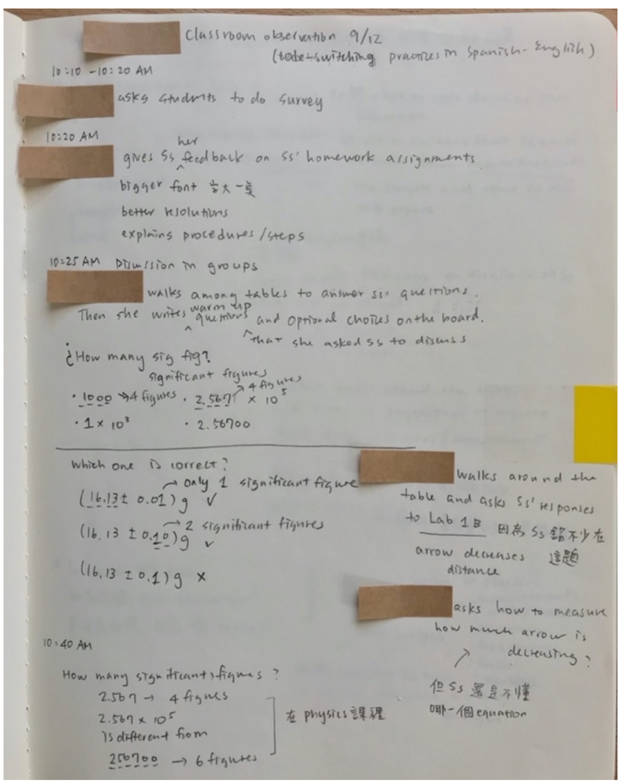
Table 3: Data sources and data collection in each field site

Field sites	Data Sources Collected
Graduate-Level University Practicum class	• Observation fieldnotes: 20 visits of one-hour lecture + 12 visits of one-hour practicum (language lab and micro-teaching practices) = **32 visits** and **32 hours** of observation • Collection of relevant documents, including assignment guidelines for mirror projects • Researcher reflexive account
CSE Practicum program for international graduate assistants (One-week online session)	• Observation fieldnotes: **5 visits** of online sessions • Researcher reflexive account
CSE Practicum program for international graduate assistants (Two-week face-to-face session)	• Observation fieldnotes: 8 visits of five-hour lecture + 2 visits of five-hour micro-teaching practices = **10 visits** + **50 hours** of observation • 40 hours of video- and audio-recordings of classroom socialization activities between program faculty and CSE international graduate assistants + 10 hours of video- and audio-recordings of micro-teaching practices = **50 hours** of digital recordings • One-hour formal interview with the program faculty member, graduate-level resource teaching assistant participant: **2 hours** of audio-recorded interviews • Frist one-hour formal interview with each of the 3 focal Physics international graduate assistant participants: **3 hours** of audio-recorded interviews • Collection of relevant documents • Researcher reflective account
Introductory Physics for Science and Engineering class	• Observation fieldnotes: 36 visits (12 weeks) of 3 two-hour Laboratory sessions + 24 visits (12 weeks) of 2 one-hour Discussion sessions = **60 visits** + **96 hours** of observation • Video- and audio-recordings of classroom socialization activities in both the three-hour Laboratory session and one-hour Discussion session : **132 hours** of video- and audio-recordings of classroom socialization activities • Second one-hour formal interview with each of the 3 focal Physics international graduate assistant participants: **3 hours** of audio-recorded interviews • Collection of relevant documents • Informal conversation with focal Physics international graduate assistant participants' and their undergraduate physics students • Researcher reflective account
Total	• 102 classroom visits and more than 178 hours of classroom observation • 182 hours of video- and audio-recordings of language socialization activities in both the CSE Practicum program for international graduate assistants and the *Introductory Physics for Science and Engineering* classes • 8 hours of audio-recordings of interviews

3.2.2.1 Data collection in Introductory Physics for Science and Engineering **class**

I wrote observation fieldnotes as a participant-observer in the three *Introductory Physics for Science and Engineering* classes. I documented *how* the three focal physics international graduate assistant participants, through the use of disciplinary spatial repertoires and mathematical symbolic systems, socialized their undergraduate physics students into the discourse practices and cultures of the physics discipline. For instance, Figure 9 is a screenshot of my observation fieldnotes recording the examples (i.e. 16.13 $\pm$ 0.01; 16.13 $\pm$ 0. 10; 16.13 $\pm$ 0.1) used by Gina (one of focal physics international graduate assistant participants, pseudonym) to teach her undergraduate students what significant figures (i.e. number of digits in value, often a measurement) are, and why significant figures are important to the degree of accuracy of the mathematical value.

Figure 9: Screenshot of my observation fieldnotes [September 12, 2017]



My observation fieldnotes provided complementary information that allowed for a more thorough contextualization of disciplinary knowledge construction and negotiation between focal physics international graduate assistants participants and their undergraduate students. Contextualization does not mean "providing context in the form of background information;" instead, I used the term to "refer to speakers' and listeners' use of verbal and nonverbal signs to relate what is said at any one time and in any one place to knowledge acquired through past experience" (Gumperz, 1992, p. 230). My observation fieldnotes helped connect the excerpts transcribed and analyzed in Chapter 4-6 to the knowledge that I acquired through my fieldwork as a participant observer.

In addition, I video recorded the classroom socialization activities between the focal physics international graduate assistant participants and their undergraduate students. I placed a tripod-mounted digital camcorder in the back corner of the classroom in order to capture the communication and interactions between the focal physics international graduate assistant participants and as many undergraduates as possible. I also carried a camcorder on my hands to capture the interactions between the focal physics international graduate assistant participants and their undergraduate students or between undergraduate students themselves in group activities. The video recordings documented moment-by-moment situated disciplinary socialization activities for micro-analysis (Mondada, 2014, 2019). These recordings allowed the 'microethnography' of conversation/discourse analysis to complement the general ethnography of participant observation (Garcez, 2017). Micro-analysis of video-recorded physics socialization activities allowed for a more thorough contextualization of how disciplinary competence are mediated through the confluence of disciplinary spatial repertoires and mathematical symbolic systems. Micro-analysis of video-recorded classroom socialization activities also suggests that linguistically-multimodally-mediated communication and interactions is best approached as primarily a discourse-level rather than a phonological, lexical, and grammatical phenomenon (Moschkovich, 2002, 2007). The meanings that emerged from physics socialization activities were thus needed to be contextualized within their temporal and spatial surroundings (Mondada, 2018).

3.3 Data transcription and data analysis

I paired the critical ethnographic approach detailed in Section 3.2 with multimodal conversation analysis to highlight the dialogic nature of socialization activities in the three *Introductory Physics of Science and Engineering* classes taught by my focal physics international graduate assistant participants. In this section, I illustrate how I used a multimodal conversation analysis to transcribe and analyze the video-recorded classroom socialization activities in the three *Introductory Physics of Science and Engineering* classes. I explain how multimodal conversation analysis offers language socialization research a robust transcription and analysis system for examining the dialogic nature of physics discourse practices that are mediated through disciplinary spatial repertoires (e.g., language, multimodalities) and mathematical symbolic systems (e.g., mathematical equations). In addition, I describe combining multimodal conversation analysis with Bakhtin's (1981) construct of dialogism (mainly, chronotope and heteroglossia) is essential to analyzing the dynamic multiplicity of physics discourse practices and instructional interactions.

Throughout the data analysis process, I focused on how meanings in physics socialization activities were mediated through the integration of disciplinary spatial repertories and mathematical symbolic systems. The analysis of chronotopic nature of physics socialization activities provides a nuanced insight into the sequential and spatial nature of disciplinary repertoires that serve as collective assemblages through which international graduate assistant participants and their undergraduate physics students construct intersubjective knowledge in a chronotopic manner (Lai, 2020). The analysis of heteroglossic nature of physics discourse practices shed new light on how competing discourses of expertise creates heteroglossic spaces for the focal physics international graduate assistant participants to challenge institutionalized ways of knowledge construction and for undergraduate physics students to form peer language socialization that may open the floor to alternative legitimate ways of demonstrating expertise in the physics community (Lai, under review).

3.3.1 Data transcription through multimodal conversation analysis

I transcribed approximately 96 hours of classroom socialization activities video-recorded in the three *Introductory Physics for Science and Engineering* classes taught by my focal physics international graduate assistant participants. The transcription conventions I used to transcribe data are shown in Appendix. In addition to annotations on language and multimodal resources, annotations on discourse features of physics socialization activities also included mathematical symbolic systems, as shown below.

In order to capture the mathematical symbolic systems and multimodal features of physics discourse practices (introduced in Chapter 2, Section 2.2.2), I thus developed a multimodal transcript method following the methodological foundations of Conversation

Analysis (Jefferson, 2004; Schegloff, 2007) to document the sequential structures of physics socialization activities. I also adopted a multimodal approach that was established in the discourse study of mathematics and sciences (e.g., O'Halloran, 2015; Lemke, 1998) to identify integrated patterns involving language (e.g., English forms), multimodal resources (e.g., gesture movements), and mathematic symbolic notations and equations written on the whiteboard situated in physics discourse practices. My goal in the transcript was to foreground the sequential organization of physics discursive practices, to study how physicists construct situated meanings and disciplinary expertise through the simultaneous use of academic registers in physics, multimodalities, and mathematic knowledge.

Conversation analysis is a theoretical and methodological approach to the study of talk-in-action, which grew out of the ethnomethodological tradition in sociology developed by Harold Garfinkel. Conversation analysts examine how individuals construct knowledge of the world through linguistic and multimodal repertoire in everyday conversation. Conversation analysts draw from ethnomethodology the concern for understanding "how the structures of everyday activities are ordinarily and routinely produced and maintained" (Garfinkel, 1967, p. 35-36). The study of conversation analysis investigates the sequential structures and organization of social interaction and participation framework. This line of research theoretically and methodologically bases on naturally occurring data and micro-analytical analyses of real world, situated, contextualized action and interaction (Sidnell, 2010). The focus on the actual instances of human conversation allows for a more thorough examination of *what* has been said and *how* it was said, rather than reporting an account of what speakers said they did and do (e.g., as a discussion of an introspection about language use) (Heritage, 1995).

The convention system that I used to transcribe the physics socialization activity data was developed by Gail Jefferson (2004) and expended by Emanuel Schegloff (2007). The transcription conventions I used to transcribe data are shown in Appendix. Detailed transcripts of naturally occurring social action and interaction allow conversation analysts to see the moment-by-moment complex nature of talk-in-action captured in recordings. Transcripts, however, are not neutral and objective representations of conversation and interaction (Ochs, 1979). As Green and his colleagues (1997) note, a transcript is "a text that represents an event; it is not the event itself. Following this logic, what is re-presented is data constructed by a researcher for a particular purpose, not just talk written down" (p. 172). Transcripts are subjective representations of talk-in-action in which a researcher needs to make decisions about what linguistic and/or multimodal features are foregrounded and backgrounded (Bucholtz, 2000). These decisions, or politics of transcription, shape how a researcher interprets the structures of interaction by making some features more visible while obscuring others (Ochs, 1979).

The subjective nature of transcriptions indicates that a researcher may transcribe her/his data differently at different times in order to analyze diverse aspects of the conversation and interaction being transcribed based on the developing sets of analysis focuses (Erickson, 2010). According to Liddicoat (2011), transcription is not "a once-for-all-time representation of talk but rather an open-ended process in which the transcript changes as the researchers' insights into the talk are refined through ongoing analysis" (p.

28). As a conversation analyst, I re-transcribed my data frequently while repeatedly listening and watching the video recordings in order to observe (see and hear) different aspects of academic action and interaction. For conversation analysts, transcription is not merely a representation of talk-in-action, but rather an analytic method that helps analysts attend to detailed features of interaction (Bolden, 2015)— that is, *what* has been said and *how* it was said (Goodwin & Goodwin, 1987; Gumperz & Berenz, 1993).

Research Question 1 on the dialogic nature of physics socialization activities led to an analytical focus on the coordination of disciplinary spatial repertories (embodied linguistic-physical-material resources) and mathematical symbolic systems. For this reason, I considered talk-in-action, along with co-occurring writing and embodied practices, to be a joint structure for the purpose of transcribing the integration of linguistic, multimodal, and mathematical characters of physics socialization activities. I transcribed each such joint structure as a single unit of transcript. Example 1 below demonstrates how I used the Transcription Conventions in Appendix to transcribe the linguistic resources of physics discourse practices in a blue line; the confluence of communicative multimodalities (e.g., pointing gesture) were noted in green; and mathematical symbolic systems (e.g., mathematical equations and images) were noted in purple. Please note that the color coding in Example 1 is to show how physics reasoning is constructed through disciplinary spatial repertoires (i.e. linguistic and multimodal features) and mathematical characteristics (e.g., mathematical equations and images) of physics discourse practices. The Excerpts presented in my Findings Chapters do not contain transcripts with any color coding in them.

Example 1: Meaning making about a physics activity through linguistic, multimodal, and mathematical features of physics discourse practices

Language

Mathematical symbolic systems

1 Kelly So we know
2 Since it has <constant angular velocity>
3 So you don't have [acceleration
4 [*points to* $\frac{1}{2}\alpha t^2$ *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$

Pointing gesture

Meaning making through disciplinary spatial repertoires and mathematical symbolic systems

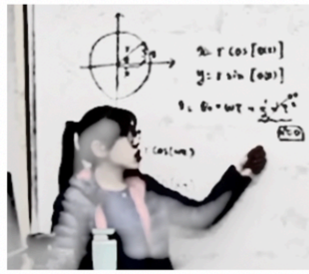


Figure 16

5 So your [angle dependent will be on the [initial condition and the [velocity
6 [*points to* θ *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$
7 [*points to* θ_0 *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$
8 [*points to* ωt *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$

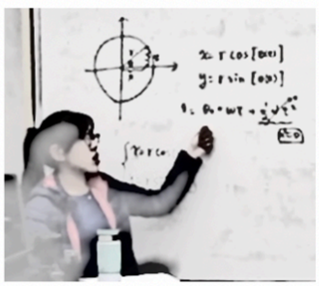


Figure 17a

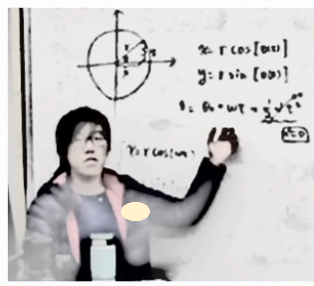


Figure 17b

9 >Right?<

Scientists (e.g., physicists, mathematicians) never make meanings with language alone. As explained earlier in Chapter 2 Section 2.2.2, meaning making is always a semiotic process as well as a material practice (Lemke, 1998). Applying Lemke's concept to my data transcription and analysis, my transcription included information on the following discourse features: the integration of disciplinary spatial repertories (language, multimodalities) and mathematical symbolic systems.

In order to illustrate the necessity of the multimodal transcription system I used, consider Example 2 below in which I have ONLY transcribed the linguistic characteristics of physics discourse practices from an excerpt of interaction in *Introductory Physics for Science and Engineering* class taught by one of my focal physics international graduate assistant participants, Kelly. In Example 2, Kelly answers her students' questions about the concept of the derivatives of $sine$ and $cosine$ functions being derived from mathematics (trigonometry) (See Appendix for Transcription Conventions).

Example 2: Transcript of linguistic features ONLY

[Classroom discourse transcript: Kelly, October 18, 2017]

1	Kelly	A. Is **that** okay?
2	Alex	↓Yeah
3	Kelly	Amplitude
4	David	Is **it**- is **it** (.) A: are maximum?
5	Kelly	↓Yes. [This is the amplitude of the: (0.2) position
6	(1.0)	
7	Brian	Where'd **that**- where'd **that** come from?
8	Kelly	[**This** one, **this** from?
9		[↓Yeah: <math>
10	Ss	[☺☺
11	Kelly	So:
12	Brian	.hh **It** came from math?
13	Kelly	Is **that** okay?
14		For all of you?
15	Alex	[↑Oh: **this** is crazy

Viewing this transcript of spoken language separated from its co-occurring communicative multimodalities and mathematics symbolic systems, it is impossible to identify what the third personal pronoun '*it*' (lines 4 and 12) as well as the demonstrative determiners '*this*' (lines 8 and 15) and '*that'* (lines 1, 7, and 13) refer to. Furthermore, it is challenging to recover from talk alone what physics and mathematical activities both Kelly and her undergraduate students were accomplishing in the transcript, such as what pragmatic message Alex (Kelly's undergraduate physics student, pseudonym) was trying to deliver with the statement sentence *this is crazy* in line 15. What does the demonstrative determiner '*this*' refer to? What thing does the adjective '*crazy*' describe?

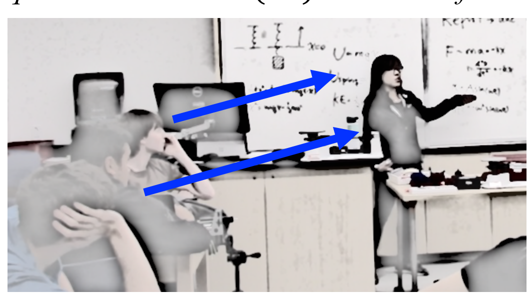
The semantic ambiguities caused by only transcribing linguistic utterances of undergraduate students can be easily resolved by also recording the synchronous context of those utterances in the form of the mathematical inscriptions written on the whiteboard, Kelly's indexical gestures, and her undergraduates' eye gaze. Transcriptions recording coordination among talk, pointing gestures, and mathematical equations and images are required to comprehend the sequential structures of physics reasoning. Example 3 demonstrates a transcription of all the linguistic, multimodal, and mathematical characteristics of the same excerpt of interaction between Kelly and her undergraduate physics students.

Example 3: Transcript of linguistic, multimodal, and mathematical characteristics

[Classroom discourse transcript: Kelly, October 18, 2017]

1 Kelly [A. Is **that** okay?
2 *points to A in the equation* $x = A\,sin\,(\omega t)$ *with her left hand*

Figure 10



3 Alex ↓Yeah
4 Kelly Amplitude

5	David	Is **it**- is **it** (.) A: are maximum?
6	Kelly	↓Yes. [**This** is the amplitude of the: (0.2) position
7		[*points to A in the equation* $x = Asin\ (\omega t)$ *with her left hand*
8	(1.0)	
9	Brian	Where'd **that**- where'd **that** come from?
10	Kelly	[**This** one, **this** from?
11		[*points to* $x = Asin\ (\omega t)$
12		[↓Yeah: <math>
13		[*opens her arms*

14		[*looks at the class and smiles to her students*

15	Ss	[☺☺
16	Kelly	So:
17	Brian	.hh **It** came from math?
18	Kelly	Is that okay?
19		For all of you?
20	Alex →	[↑Oh: **this** is crazy
21		[*scratches his head*

22	Kelly	So, you have [this
23		[*points to* $\frac{d^2x}{dt^2} = -\ \omega sin\ (\omega t)$
24	Brian →	<u>Don't</u> worry=
25	Kelly →	=I know

26 So, you have [this equation
27 [*points to* $\frac{d^2x}{dt^2} = -\omega sin\ (\omega t)$

In Example 3, in line 9, Brian (undergraduate physics student, pseudonym) uses the demonstrative determiner *that* in his question asking where that would come from. In line 10, Kelly utters *this form* ending with a rising intonation, simultaneously pointing to the mathematical equation $x = sin\ (wt)$ written on the whiteboard. Kelly's pointing gesture transcribed in line 11, indicating the referent of Kelly's use of demonstrative determiner *this* in line 10— that is, the equation $x = sin\ (wt)$— is apparent from reading this multimodal transcript. Thus, we as readers have a clearer idea of what question Brian asks and how Kelly answers. Furthermore, the communicative act as well as the physics activity are recorded.

Beyond correcting these apparent deficiencies of Example 2, additional nuances can be discerned in the multimodal transcript in Example 3. For instance, we can see how certain communicative acts are achieved linguistically and multimodally, such as the statement sentence *this is crazy* uttered by Alex recorded in line 20. What does the demonstrative determiner '*this*' refer to? Right before the beginning of the physics activity transcribed in Examples 2 and 3, Kelly had asked her students if they had learned the derivatives of *sine* and *cosine*. Kelly then wrote a number of mathematical equations to teach the class how to plot in the derivatives of *sine* and *cosine* into the differential equation, in order to obtain the equation $x = Asin\ (\omega t)$. Students who had had no prior education about what the derivatives of $sine$ and $cosine$ functions (trigonometry in mathematics) were could easily feel lost and anxious during the interaction recorded in Examples 2 and 3. From reading the multimodal transcript in Example 3, we have information allowing us to infer that the demonstrative determiner '*this*' means all the relevant procedures of derivatives of $sine$ and $cosine$. Thus, Alex's statement '*this is crazy*' could either be interpreted as communicating how complex the mathematics procedures are for Alex, or the confusion of students lacking knowledge of what all the relevant procedures of derivatives of $sine$ and $cosine$ are.

Transcribing the linguistic, multimodal, and mathematical semiotics of physics discourse practices is thus an important component of this dissertation project. As Mondada (2019) indicates, a series of challenges that conversation analysts may encounter include how the interactional order can be further described and systematized to visually demonstrate the integration of complex linguistic and spatiotemporal features of embodied discursive practices. I had to decide how to describe co-occurring writing and communicative multimodalities (e.g., pointing gestures), as movements of hands and body do not have a standard orthography; also, participants' embodied actions and responses are in constant motion as they interact. I had to decide which of these movements deserved to be foregrounded in the transcript. In many cases, this led me to pay closer attention to my study participants' simultaneous use of quantitative mathematics and multimodalities. Alongside the data transcripts, I decided to include images selected from the video recordings record the confluence of mathematics writing on the whiteboard and communicative multimodalities in physics socialization. For instance, the pointing gesture illustrated in Figure 9 in Example 3 demonstrates how the derivatives of $sine$ and $cosine$ functions in trigonometry are visually mediated and indexed through Kelly's gesture movements.

3.3.2 Data analysis

After transcribing all the video-recorded socialization activity data collected in the three *Introductory Physics for Science and Engineering* classes, I printed out the multimodal transcripts for data reading and data analysis. (Multimodal) Conversation analysis is data-driven approaches to talk-in-action research— that is, (multimodal) conversation analysts "work from data to theory not from theory to data" (Liddicoat, 2011, p. 70). This methodological foundation gives a unique systematic structure to analyze the joint structures of disciplinary spatial repertoires and mathematical symbolic systems in physics socialization activities. In this dissertation study, data analysis involved two phases: (1) numerous (unmotivated) readings and (2) application of Bakhtin's (1981) construct of dialogism to examine the chronotopic and heteroglossic natures of physics discourse practices and instructional interactions.

Data analysis phase I. Unmotivated reading is a process of noticing discursive features of talk-in-action, which may be quite unremarkable in themselves (Sacks, 1984; Schegloff, 1996). Unmotivated reading is not on purposeless reading of the data but rather an "openness to what the data presents rather than inspecting the data to find instances of a phenomenon (Liddicoat, 2011, p. 71). When doing unmotivated reading, I paid close attention to *what* academic actions and interactions were being performed and *how* those actions and interactions were accomplished within socialization activities between the focal physics international graduate assistant participants and their undergraduate students. I also paid close attention to the linguistic, multimodal, and mathematical features of the discourse practices and *how* these features mediated socialization activities. Unmotivated reading assisted me as a conversation/discourse analyst became familiar with what my data presented without constraining what could be seen as relevant in the data.

Unmotivated reading can also be problematic, as the researcher does not approach his/her data from a completely natural position (e.g., Ten Have, 2007). Thus, keeping an analytic memo throughout the analysis process, including in unmotivated reading, is recommended (Sidnell, 2010). In the present dissertation project, unmotivated reading was a process in which I watched and listened to the recorded data numerous times. Simultaneously, I also read through my multimodal transcripts and observation fieldnotes as well as wrote analytic memos in order to observe and identify socialization patterns in physics communication and interaction. I immersed myself in the data to let the data speak to me rather than imposing an interpretation on the data. When reading the multimodal transcripts in this way, I focused on:

(1) The sequence organization of physics socialization activities and the ways how they are developed and structured. This included identifying where a piece of physics or mathematics knowledge began and ended in the transcript; how the sequence organization of physics discourse practices was constructed; what academic actions and interactions the sequence accomplished; and whether there was any earlier or relevant talk related to the beginning of the sequence analyzed or later talk following the end of the sequence analyzed.

(2) The ways in which turn-taking and repair work operate in physics socialization activities. This included identifying the participation framework within physics socialization activities, where and how a turn was initiated and responded by participants (e.g., focal Physics international graduate assistant participants and their undergraduate students), and whether there were any pauses or overlapping talk when participants competed with each other for disciplinary expertise and memberships. This also included identifying where a repair occurred, what seemed to lead to that repair (e.g., language proficiency, lack of physics knowledge); who indicated that there was a physics or mathematics problem to be repaired, who did that repair, and how the repair was accomplished.

Simultaneously, I made entries into my analytic memos about socialization patterns and participation framework.

Within the field of Conversation Analysis, turn-taking is a key component of interactional practices. Without turns, there is no interaction. The basic unit of a turn is the turn construction unit (TCU). A turn construction unit can be a word, a phrase, a clause, or a sentence that completes a communicative act (Schegloff, 2007; Sidnell, 2010). An important feature of a TCU is its projectability, which allows the recipient to calculate or predict its possible ending. A TCU can be grammatically complete, intonationally complete, or pragmatically complete (Ford & Thompson, 1996). Consider Example 4 below, showing a TCU in which David (undergraduate physics student, pseudonym) initiates a turn by asking his international graduate assistant Kelly what the physics notation A is in line 5. Kelly answers his turn by uttering the word *yes*. She further provides the meaning of the physics notation A (amplitude of a position) within the same turn in line 6. Concurrently, Kelly points to A to visually show its position in the equation and its relation to other mathematical symbols (line 7). Example 4 illustrates how I further defined a turn construction unit as the integration of disciplinary spatial repertoires and mathematical symbolic systems that constructed a complete meaning in physics socialization activity (Lai, in progress).

Example 4: Turn construction unit through joint structure of spatial repertoires and mathematical symbolic systems

[Classroom discourse transcript: Kelly, October 18, 2017]

1	Kelly	A. Is **that** okay?
2		*points to* A *in the equation* $x = A\ sin\ (\omega t)$ *with her left hand*

Figure 10

3	Alex	↓Yeah
4	Kelly	Amplitude
5	David	Is **it**- is **it** (.) A: are maximum?
6	Kelly	↓Yes. [**This** is the amplitude of the: (0.2) position
7		[*points to A in the equation* $x = Asin\ (\omega t)$ *with her left hand*

Data analysis phase II. In the phase II, I combined the multimodal conversation analysis described above with Bakhtin's (1981, 1986) dialogism of chronotope and heteroglossia to examine the dynamic multiplicity of discourse practices and socialization activities in the three *Introductory Physics to Science and Engineering* classes taught by the focal physics international graduate assistant participants. Adding the theoretical concepts of Bakhtin's dialogism on the multimodal conversation analysis assisted me to attend to detailed features of physics communication and interactions (textual form, discursive structure and organization) at all levels. That is, the phase II analysis was centrally concerned with the ways linguistic-multimodal-mathematical characteristics of discourse practices and instructional interactions are intertextually mediated, and how these characteristics are linked to academic genres at both the local level and institutionalized ideologies at the broader societal level.

In Chapter 4, findings will answer the Research Question 1 and its sub question 1(a), concerning how meaning making in physics socialization interaction between the focal physics international graduate assistant participants and their undergraduate students is mediated through disciplinary spatial repertoires and mathematic symbolic systems, chronotopically and multimodally. I applied Bakhtin's (1981) construct of chronotope to analyze the simultaneous and sequential organizations of physics instructional practices by focal international graduate assistant participants, highlighting the chronotopic nature of physics discursive and instructional practices that are ordered in sequence in interaction. The mediating orders of physics instructional activities reside in an intertextual network, which involves ways of expressing disciplinary expertise in physics, ways of acting as a physicist and graduate instructor, and ways of voicing the *self* that involves both the social and institutional identities. A focus concerned with the (re)contextualization process of text/discourse production and distribution allowed for a closer examination of how discipline-specific and institutional ideologies, linguistically and multimodally, shape discursive practices between the focal Physics international graduate assistant participants and their undergraduate students.

In Chapter 5, findings will answer the Research Question 1 and its sub question 1(b), addressing the challenges associated with physics-specific disciplinary discursive and ideological practices that the focal physics international graduate assistant participants encountered in their instructional communication and interactions with their undergraduate students, and how both the focal physics international graduate assistant participants and their undergraduate students engaged with those challenges to facilitate the socialization processes in physics contexts. I applied Bakhtin's (1981) construct of heteroglossia— particularly, its relation to indexicality, tension, and multivoicedness— to examine the heteroglossic nature of physics discourse practices. The analysis focused on the competing discourses of expertise in physics socialization activities which intertwined with participants' past experiences, present on-going involvements, and future responses, reflecting a centripetal-centrifugal tension in the heteroglossic context of physics discourse. In the present dissertation study, this tension emerged as the juxtaposition between disciplinary content experts and U.S. classroom discourse novices seemed to create interactional consequences for the focal physics international graduate assistant participants and their situated identities as graduate instructors vulnerable to the negotiation of their subject-area knowledge and expertise.

Throughout the processes of data transcription and analysis, I had regular and consistent dialogues with the focal physics international graduate assistant participants for member checking and validation. These focal participants also answered any physics and mathematical questions that I had throughout the data analysis process. Such dialogues with them not only strengthened the trustworthiness of the study but also kept our negotiations and conversations ongoing so that I could see more fully their socialization experiences into becoming competent physicists in their disciplinary communities.

Chapter 4

Chronotopic nature of physics discourse practices and socialization activities

"I" is not the name of a person, nor "here" of a place, and "this" is not a name. But they are connected with names. Names are explained by means of them. It is also true that it is characteristic of physics not to use these words.

L. Wittgenstein, Philosophical Investigations (1958, p. 123)

In order to enter our experience (which is social experience) they must take on the form of a sign that is audible and visible for us (a hieroglyph, a mathematical formula)... Without such temporal-spatial expression, even abstract thought is impossible. Consequently, every entry into the sphere of meanings is accomplished only through the gates of the chronotope.

Bakhtin, M. M. The dialogic imagination: Four essays. Vol.1 (1981, p. 258)

Chapter 4 answers the Research Question 1 by examining the chronotopic nature of physics discourse practices and instructional activities between bi/multilingual international graduate assistants and their U.S. undergraduate physics students. This chapter also addresses the sub question 1(a) that considers how meaning making in physics socialization activities is mediated through disciplinary spatial repertoires and mathematic symbolic systems in a chronotopic manner.

In this chapter, I apply Bakhtin's (1981) construct of 'chronotope' (literally 'time-space') to examine how disciplinary knowledge is constructed between bilingual physics international graduate assistants and their undergraduate students through the chronotopic (re)contextualization of their prior physics reasoning and future applications in present discussions about a physics event. As explained in Chapter 2 Section 2.3, this chronotopic (re)contextualization process requires a physicist's interpretive journey through the following discursive features: the integration of discipline-situated spatial repertoires (i.e. academic language in physics, multimodalities) and mathematical symbolism and images (e.g., the Newton's Second Law of Motion equation $F = ma$). The *time* structure (i.e. the interplay between prior physics reasoning and future responses in current on-going involvements) and *space* structure (i.e. places where different modes of discursive practices are demonstrated sequentially or simultaneously, physically or bodily) are what I term the *chronotope* of physics discourses. The present study asserts that an analysis of the chronotopic nature of diverse spatial repertoires and mathematical knowledge is essential to understanding the dynamic multiplicity of physics discourse practices and socialization activities led by international graduate assistants.

As detailed in Chapter 3, instructional activities mediated by spatial repertoires and mathematical symbolic systems between the three focal physics international graduate assistant participants and their U.S. undergraduate students were video recorded. Data were analyzed through combining methods of multimodal conversation analysis with Bakhtin's (1981) construct of chronotope. Following Bakhtin, the chronotopic activities of physics instructional practices can be seen as the confluence of disciplinary spatial repertoires and mathematical symbolism and images that international graduate assistants used to teach undergraduate physics students to link prior logical reasoning and future applications in present activities about physics events. In the instructional interactions where disciplinary meanings could not be constructed through the medium of the English language, other resources of spatial repertoires (e.g., translingual practices, visual displays, or embodied hand movements) were used by international graduate assistants, jointly with the mathematical symbolism and images, to move the instruction forward. This chapter presents data that suggests international graduate assistants' competence in physics instruction involves interweaving sequential and simultaneous chronotopes of physics discourse practices to engage undergraduate physics students in meaning making and developing disciplinary expertise. I conclude this chapter with a discussion on how chronotopic nature of physics discourse practices is related to one another and to the disciplinary context of physics, and how these chronotopic practices shape the meaning making within physics socialization activities.

4.1 Chronotopes of physics discourse and instructional practices

This section examines the simultaneous and sequential chronotopes of physics discourse and instructional practices that are mediated through the confluence of disciplinary spatial repertoires and mathematical symbolism and images. I present multimodal conversation analysis of physics instructional activities, organized according to: (1) how physicists use, or ‘travel through,’ disciplinary spatial repertoires and mathematical symbolic systems to construct meanings and (2) multidiscursive practices and visual displays as parts of the chronotopic activities of physics instructional practices. Central in this discussion is how chronotopic activities facilitate physics instruction and serve as spaces for international graduate assistants to socialize undergraduate physics students into the discipline’s community of practice and profession of physics.

4.1.1 Meaning construction in physics through spatial repertoires and mathematics

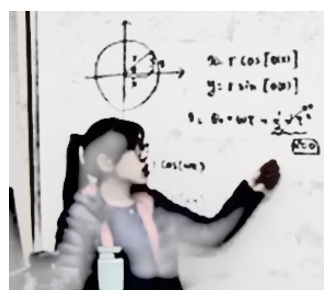
Meaning making in physics discourse and instructional practices resides in an ‘intertextual network’ (Bakhtin, 1986), which is constructed through the (re)contextualization of disciplinary spatial repertoires (i.e. academic language in physics, multimodalities) and mathematical symbolism and images. (Re)contextualization is a process through which a text or utterance is extracted from its original context and inserted into a new one. As these texts or utterances enter a new context, new meanings are situationally signified. The intertextual features of physics discourse practices are in constant dialogue with each other— that is, through their intertextual readings, physicists connect prior texts, multimodal materials, and mathematical equations and images to new meanings that become salient in the specific physics activity that is being discussed at the present moment. This contextualization practice is evident in Excerpt 1 below, where Kelly instructs her students how rotational quantities such as the angle of rotation θ, angular velocity ω, and angular acceleration α are related to one another in rotational kinematics. Kelly teaches her students how to apply rotational kinematic equations to solve position vector questions (see Transcription Conventions in Appendix).

Excerpt 1: So you write your *x* and *y* like this

[Classroom discourse transcript: Kelly, November 15, 2017]

1 Kelly So we know
2 Since it has <constant angular velocity>
3 So you don't have [acceleration
4 [*points to* $\frac{1}{2}\alpha t^2$ *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$

Figure 12



5 So your [angle dependent will be on the [initial condition and the [velocity
6 [*points to* θ *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$
7 [*points to* θ_0 *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$
8 [*points to* ωt *in the equation* $\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$

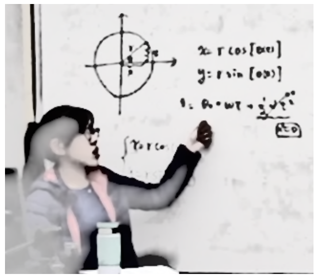


Figure 13-1

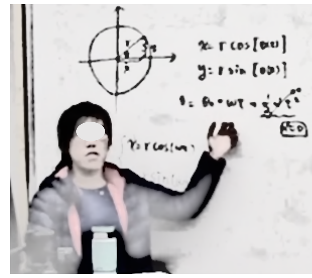


Figure 13-2

9 >Right?<

10 So you can write your (0.4) [x and y like this

11 [*adds plus maker* $+$ *and* θ_0 *to complete the* x *and* y *equations*

$$\begin{cases} x = rcos(\omega t = \theta_0) \\ y = rsin(\omega t = \theta_0) \end{cases}$$

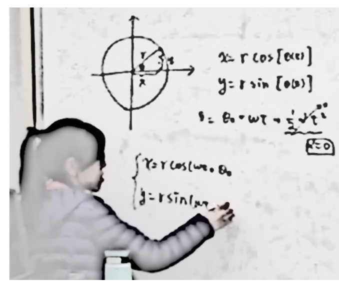


Figure 14

12 So: you have the position

(0.4)

13 So when you want to get velocity, your just use the derivatives we have

14 So you will get [this one and [this one

15 [*points to*

$$\begin{cases} v_x = \frac{d_x}{d_t} = -\omega rsin(\omega t) \\ v_y = \frac{d_y}{d_t} = \omega rcos(\omega t) \end{cases}$$

16 [*points to*

$$\begin{cases} a_x = \frac{d^2x}{dt^2} = -\omega^2 rcos(\omega t) \\ a_y = \frac{d^2y}{dt^2} = -\omega^2 rsin(\omega t) \end{cases}$$

In Excerpt 1, in line 1, Kelly starts her instruction by uttering— *so we know*— which orients the class to the background regarding the rotational kinematics that *we* as physicists should know; in line 2 that knowledge is conveyed in the clause *since it has constant angular velocity*. In this clause, Kelly grammatically constructs the physical event of rotational kinematics as experiencer by using the third person singular pronoun *it* to refer to the physical event of rotational kinematics, and by selecting a predicate *has* to indicate that the angular velocity of the physical event being discussed is constant. Because of this first scientific condition (i.e. the physical event of rotational kinematics has no constant angular velocity), in line 3, Kelly states *you don't have acceleration*. Here, an indeterminate referent grammar— an animate pronominal subject or the second person plural pronoun *you*, plus an inanimate physical event predicate in negative mode *don't have acceleration*— is used by Kelly (the more experienced physicist) to symbolically position her students (the less experienced physicists) in an imagined realm of a physical event in which the angular velocity of that event is constant (Ochs, Jacoby, & Gonzales, 1994; Ochs, Gonzales, & Jacoby, 1996). Simultaneously, in line 4, and shown in Figure 12, Kelly uses the back of her left hand to point to the sign $\frac{1}{2}at^2$ symbolically indexing the acceleration in the equation $\theta = \theta_0 + \omega t + \frac{1}{2}at^2$ written on the board. In doing this, Kelly visually shows to her students where the symbol for acceleration is located in the equation and its relation to other physical quantities represented there (see Figure 12).

In line 5, due to the second known scientific condition (i.e. no acceleration exists when the angular velocity of a rotational kinematics event is constant), Kelly states *your angle dependent will be on the initial condition and the velocity*. Here, again, the indeterminate referent grammar— an animate pronominal subject or the second person possessive determiner *your* and the noun phrase *angle dependent*, with the inanimate physical event predicated in future tense *will be on the initial condition and the velocity*–– is used by Kelly (more experienced physicist) to symbolically position her students (less experienced physicists) in an imagined realm of a physical event in which a referent, the angle θ, is related to the initial condition or position of the angle θ and the second referent, the angular velocity ωt. Simultaneously, in line 6, Kelly uses the back of her left hand to point to the initial position of angle θ symbolically indexed through the sign θ_0, and then the angular velocity ωt indexed by the sign ωt in the equation $\theta = \theta_0 + \omega t + \frac{1}{2}at^2$ written on the board. In doing this, Kelly visually demonstrates to her students the relations between initial position of angle θ, angular velocity ωt, and other physical quantities in the equation (see Figures 13a and 13b).

Under the already known first and second scientific conditions, and after questions regarding the initial position of angle θ and the angular velocity ωt are solved, in line 10, Kelly instructs the class on the fixed x and y axes of rotation by stating *you can write your* x *and* y *like this*. Here, Kelly employs the second person plural pronoun *you* and the possessive determiner *your*, plus mathematical expression x and y (axes), to reposition her students as physicists and experiencers of the physical event presently under discussion. The predicate *write your* x *and* y used by Kelly directs the students' attention to the rotation of axes equations that are already written on the board. At the end of the phrase, the referring expression *this* is indexed to it referent through the co-occurring writing of mathematical equations (i.e. $x = rcos(\omega t = \theta_0)$ and $y = rsin(\omega t = \theta_0)$) and the embodied communicative multimodalities of Kelly's pointing gesture using the black marker to point to the equations (see Figure 14). In doing this, Kelly teaches her students how to apply mathematical equations step-by-step to solve an angular position in rotational kinematics and socializes her students into the mathematical expressions in physics that establish relationships between variables within a mathematical equation which represent specific properties of a physics activity (Opfermann, Schmeck, & Fischer, 2017).

Excerpt 1 illustrates the sequential structure of meaning making in physics socialization activities, mediating through referential use of disciplinary spatial repertoires and mathematical symbolic systems. As stated above, physicists frequently (re)contextualize both prior texts and future applications in order to understand new meanings that become salient in present communication while the old meanings still exist in the background. Here, mathematic symbolic systems (e.g., equations and notations) are designed semiotic resources which are different from human languages, representing a disciplinary-situated liaison between a symbol or symbolic expression (signifier) and a precise semantic meaning (signified) in physics. The critical issue of physics reasoning is not an individual mathematic symbolic notation and equation, but rather the systematic ways in which the notations and equations are organized logically, step-by-step, often along with spatial repertoires, to create meanings and develop argumentation reasoning.

4.1.2 Linking physics reasoning and mathematics through spatial repertoires

Using the framework of Bakhtin's chronotope (1981), meaning making connects prior experiences and future applications to present activities through spatiotemporal links. Like many other bi/multilingual individuals, international graduate assistants are always situated and processing their thoughts dialogically, as their prior discourse practices within the physics discipline (may have been in entirely different languages other than English) are ever present in current activities (Rosborough, 2016). In the present study, in some international graduate assistant-led instruction activities, assistants paused in conversation due to the co-occurrence of different discursive registers in their backgrounds and undergraduates' backgrounds of primary physics education. To move instructional practices forward in such instance, translingual practices (Canagarajah, 2017, 2018) then naturally occurred where international graduate assistants switched to their first languages and simultaneously used embodied communicative multimodalities to verbally explain and visuospatially demonstrate a physical concept. Such translingual practices in instruction are exemplified in Excerpt 2, where Gina tries to locate an equivalent term in English for her translingual use of the term *vínculo* from Argentinian Spanish. Prior to the instructional activity in Excerpt 2, Gina had taught her students physics concepts and mathematical equations concerning Newtons' Second Law of Motion, particularly the constructs tension (T) and acceleration (a) and their directions acting on objects.

Excerpt 2: Tension is just (0.2) is what you call *vínculo*

[Classroom discourse transcript: Gina, October 10, 2017]

1	Gina	Tension and acceleration [are the <↑un↓known>
2		[*writes symbols* T_1 *and* a *on the board*
3		We want [a
4		[*points to the symbol* a *with right index finger*
5		[Tension is just-
6		[*moves right hand to make a go-away movement*

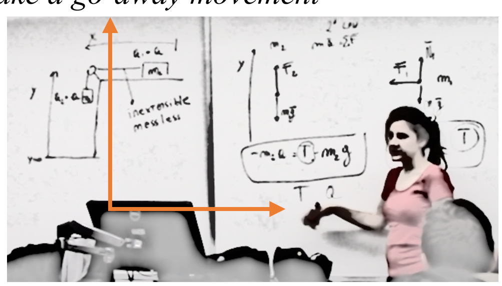
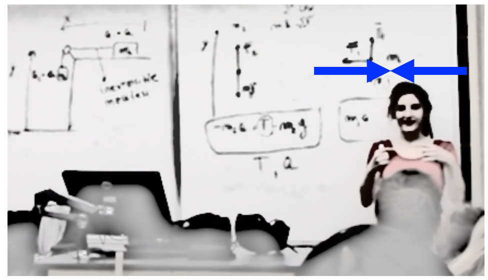


Figure 15

7		(0.2) is what you call <vínculo>
8		[°What would you say that?°
9		[*looks around the class*
10	(0.8)	

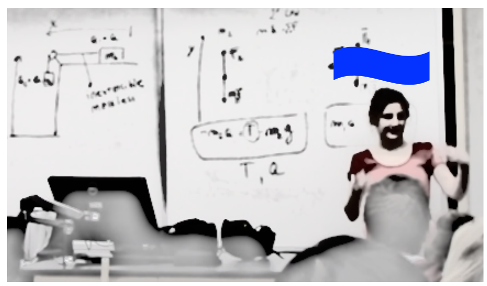
11 Adam→ Useless?
12 Gina [Hmm?
13 [*looks at Adam*
14 Adam °Useless?°
15 Gina >No, no,< vínculo-
16 → [It's something that (.) matches the masses
17 [*looks at Adam and moves both index fingers horizontally to imitate two objects are on equilibrium status*

Figure 16



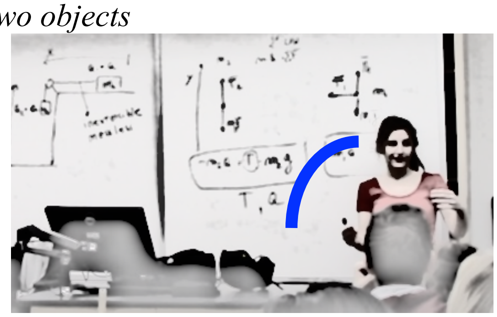
18 [They are not independent
19 [*looks at Adam, moves both hands vertically to imitate two objects are reaching to an equilibrium status*

Figure 17



20 [They are (0.2) °/inkyletɪd/°
21 [*looks at the class and moves right hand to make an arc imitating the string connecting the two objects*

Figure 18



22 Dave→ Proportion?
23 Gina [>No, no<
24 [*looks at Dave*
25 Fred → Dependent?
26 Gina De:pendent

27 [*looks at Fred*
28 ↓Yeah, co-related, [whatever you want
29 [*looks at the class*
30 <Nothing> (0.2) [makes them interlocked
31 [*points to the string connecting objects* m_1 *and* m_2

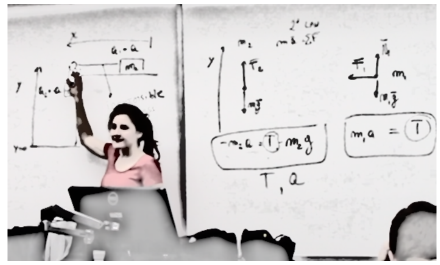


Figure 19

32 (0.4)
33 If [this string didn't exist
34 [*points to the string connecting objects* m_1 *and* m_2
35 (0.2) <then> [this] is independent from [this one]
36 [*points to object* m_2] [*points to object* m_2]
37 The acceleration is about (0.2) one opposite from the other
38 Nothing
39 → So, [this is the one that connects them
40 [*points to the string that connects objects* m_1 *and* m_2
41 That's why we write [acceleration like this way, tension, this way, etc.
42 [*points to the equation* $-m_1a = T - m_2g$

Figure 20

In Excerpt 2, Gina informs her students that tension and acceleration are the two unknown forces in the mathematical equation $-m_1a = T - m_2g$. Between these two unknown forces, tension can be ignored because the tension force acting on the objects m_1 and m_2 is equal. To explain this physics concept, in line 6, Gina waves her right hand to make a go-away gesture (see Figure 15) and then in line 7 utters an Argentinean

Spanish term *vínculo*. In line 9, Gina pauses in instruction and looks around the class for translation suggestions. In line 11, one student, Adam, mutters the word *useless* probably based on his intertextual reading and interpretation of Gina's go-away hand movement. However, the word *useless* is not equivalent to *vínculo*.

Gina self-initiates a new turn to self-repair (Wong, 2000) the misunderstanding caused by the word *vínculo*. When she utters the literal meanings of *vínculo*— that is, *something matches the masses* (line 16), *they are not independent* (line 18), and *they are /inkyletɪd/* (line 20)— simultaneously, Gina moves both hands to represent those meanings. In line 17, Gina first moves both her index fingers horizontally to imitate the equilibrium status between two objects (see Figure 16). In line 19, she moves her both hands vertically to imitate two objects are reaching an equilibrium status (see Figure 17). In line 21, she then moves her right hand to visually gesture an arc to imitate a string connecting the two objects (see Figure 18).

In response, Gina's students try to co-construct the meanings of *vínculo* based on their intertextual readings and interpretations of Gina's translingual practice and embodied hand movements of *vínculo*. In line 22, another student, Dave, says the word *proportion*, probably based on his interpretation of Gina's hand gesture in the prior turn imitating two objects reaching to an equilibrium status. Dave may not interpret Gina's hand movement as two objects reaching balance; instead, he may interpret Gina's hand gesture as a mathematical comparison between two numbers or equivalent ratios. In line 25, another student, Fred, says the word *dependent* with a raising tone. Fred's interpretation may be based on his Spanish language proficiency, his interpretation of Gina's hand gesture movement, and Gina's responses to his other peers in the prior turns.

In line 26, Gina accepts the word *dependent* and in line 28 further concludes this translingual activity by giving one more word option, *co-related*.

Towards the end of instruction and before the student experiment activity, Gina returns to the free-body diagram drawn on the whiteboard to verbally explain and visually demonstrate a physics/mathematical concept— that is, the constraint equation between two variables/objects that are dependent on each other. As Gina says in line 30 *Nothing (0.2) makes them interlocked*; in line 31, simultaneously, she points to the string on the diagram that connects the objects m_1 to m_2. Then, after a short pause, in line 33, Gina says if the two objects were not tied by the string; in line 34, concurrently, Gina points to the string drawn on the whiteboard that ties the two objects. In lines 35 and 36, Gina states, *<then> this is independent from this one*, concurrently pointing to each object drawn on the whiteboard. In line 37, Gina concludes that then the acceleration forces acting on both objects would be in opposite directions, thus no tension would be caused by the string.

In line 39, Gina further points out that the objects m_1 and m_2 are tied by the string, simultaneously pointing to the string. In line 41, she states her conclusion, that she has shown why the relationship between acceleration and tension is written in the constraint equation $-m_1 a = T - m_2 g$, which can then be used to solve for the unknown tension and acceleration forces. Here, the tension force caused by the string is indexed through the referring expression *this way* and simultaneously through Gina's embodied communicative multimodality, a pointing gesture to the string on the diagram (shown in Figure 19) (Goodwin, 2018). By using this physics reasoning about constraint features and her use of spatial organization, Gina shows to her undergraduates the reasoning underlying the mathematical equation (i.e. $-m_1 a = T - m_2 g$) which refers to the physics relations between tension and acceleration and their directions acting on objects (see Figure 20).

Thus, Excerpt 2 presents first the translingual practices initiated by the international graduate assistant Gina to engage her undergraduates to co-construct meanings in English for the word *vínculo*. When translingual meaning making could not be achieved through linguistic means, Gina's gesture movement (multimodal resources of spatial repertoires) served as spatiotemporal links for situated meaning making and facilitated Gina's physics instructional practices. The construct of chronotope helps us see how Gina's simultaneous use of verbal explanation and embodied gesture engaged student participation in physics instructional activities and maintain the sequential chronotope in instructional practices, engaging the joint attention of international graduate assistants and their undergraduate students as co-contributors to meaning making (Rosborough, 2016).

As I discussed in Chapters 2 and 3, physicists almost never make meanings with language alone. Meaning making is virtually always a semiotic process as well as a material practice (Lemke, 1998). In physics socialization activities, multimodal resources of spatial repertoires can provide straightforward contextualized information for physics reasoning about the symbolic formulations of physics and/or mathematics entities and relations (e.g. directions of different kinds of forces). Excerpt 3 below illustrates the joint use of experimental materials (multimodal resources of spatial repertoires) and mathematical equations and images, as Ian works with a group of three students on their error analysis concerning the forces in equilibrium (e.g. gravity, tension, and friction).

Prior to the discussion activity in Excerpt 3, one female student in the group has asked Ian for advice about why their quantitative data failed to align with their predicted equations, and how they could theorize their error analysis using Hooke's Law and mathematical equations. In Excerpt 3, as Ian (as a more experienced physicist and the course instructor) verbally explains to his students how Hooke's Law and academic registers in physics can be applied to the student error analysis, he uses classroom materials for student physics experiments— including a meterstick, two pulleys, two table clamps, string and three mass sets— to visually demonstrate how academic registers in physics and mathematical symbolic systems are linked together.

Excerpt 3: This tension must balance the gravity

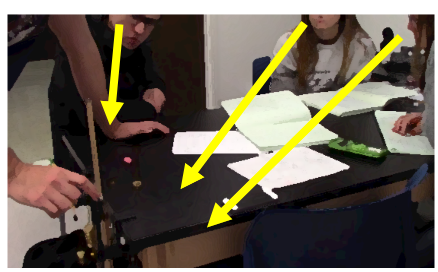
[Classroom discourse transcript, Ian, November 1, 2017]

1 Ian We are assuming
2 [$2T$, $sin\theta$ equals to big Mg, then t equals to mg
3 [*writes equation* $2Tsin\theta = Mg$ *and equation* $T = mg$ *on Zac's Lab notebook*

Figure 21

4 *adds symbol* T *to the visual image of the equilibrium system to show the tension forces working on different mass objects*
5 However, what if eh:
6 [Due to friction, and pulley, and lots of things
7 [*uses his right index finger to point to one of the pullies*

Figure 22



8 [(0.2) which make this *T* no longer (.) the same like this one
9 [*uses his right fingers to point to the two T*s *marked on the visual image of equilibrium system on Zac's Lab notebook*

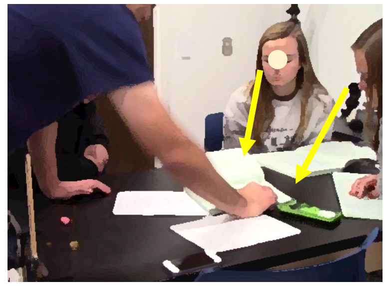


Figure 23

10 >It< could happen
11 Zac ↓Oh
12 Ian That's eh most possible error you can have
13 Because we won't have error at [here or at [here
14 [*uses his right index finger to point to the set of central mass objects*
15 [*uses his right index finger to point to the set of left-side mass objects*

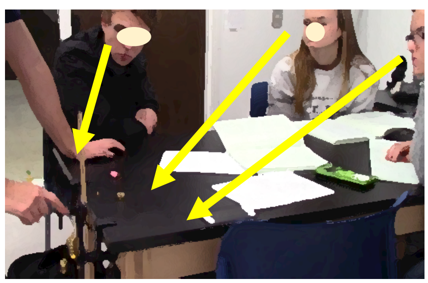


Figure 24-1

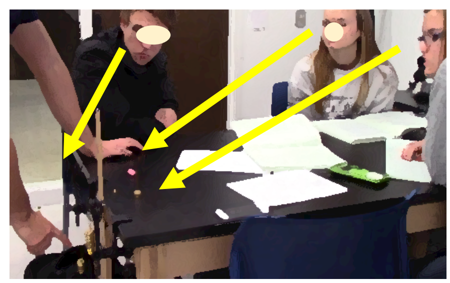


Figure 24-1

16 Because this-
17 This string should eh
18 [This eh tension (.) must (0.2) [balance the gravity
19 [*uses his both index fingers to point to the strings that holds both the right- and left-side mass objects*
20 [*use his left index finger to point to the set of left-side mass objects*

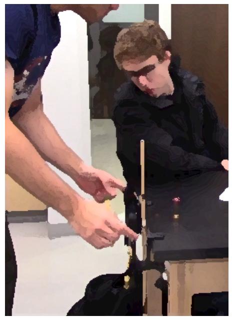


Figure 25-1

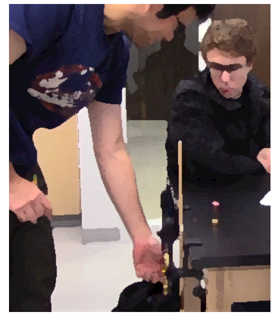


Figure 25-2

21 Zac ↓Yeah
22 Ian There is no extra force, like friction
23 There is no something like that
24 Either [here or [there
25 [*points to the central mass objects*
26 [*points to the left-side mass objects*
27 So, thing must happen like [here
28 [*uses his pencil to point to the left-side pulley and then the right-side pulley*

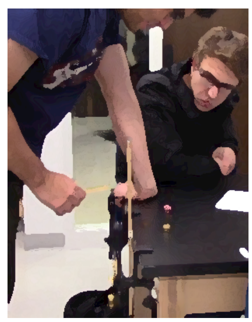


Figure 26-1

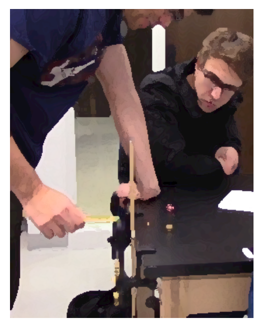


Figure 26-2

29 That's eh
30 That's an error analysis

In Excerpt 3, in line 1, Ian says *we are assuming*. Here, the physicist-centered grammar—the first person plural pronoun *we* plus the inanimate physics event predicate *are assuming*— is used by Ian (as a more experienced physicist) to symbolically position his students (as less experienced physicists) in an imagined realm of a physics event in which tensions between objects caused by connecting strings in the x and y-directions are equal, so the forces in the y-direction can be symbolically represented by the mathematical equation $2Tsin\theta = Mg$ which can be simplified as $T = mg$. In line 2, Ian utters the mathematical equations $2Tsin\theta = Mg$ and $T = m$. Simultaneously, in line 3, Ian writes the equation $2Tsin\theta = Mg$ and $T = mg$ on Zac's (Ian's student) Lab notebook to visually and mathematically demonstrate the physics event being discussed (tension forces caused by the string reaching equilibrium status). In doing this, Ian visually shows his students where the tension forces caused by the string are symbolically represented by mathematic symbols and their relations to other physics quantities (the ratio of the opposite side of the hypotenuse $sin\theta$, weight of the mass object M, and gravity g) in the equations (see Figure 21).

In line 6, Ian hypothesizes a different condition— what if there is a change in the friction force or in the weights of the mass objects— in this discussed physics event. In line 6, as Ian utters the phrase *due to friction, and pulley, and lots of things*; simultaneously, in line 7, Ian points to the right-side pulley on the table (that is, the classroom materials designed for student physics experiments) to visuospatially exemplify where other potential forces can influence the equilibrium status while his students gaze at his indexical pointing gesture (see Figure 22) (Gerofsky, 2011; Roth, 2000). The student gaze and instructor indexical pointing gesture contribute to the joint attention in physics socialization activities (Goodwin, 2018). Under the indicated hypothesized condition, the tension forces caused by the strings would be changed because of some potential influences caused by other forces. Thus, in line 8, Ian says those potential influential forces would *make this T no longer the same like this one* uttered (stressing the physics quantity T). Concurrently, as shown in line 9 and Figure 23, Ian uses his right fingers to point to the two *T*s marked on the visual image of the equilibrium system on Zac's Lab notebook. Here, there are two different tension forces caused by different weights of the mass objects— one is the mass object hanging on the left string (*this T*) and the other is the mass object hanging on the right string (*this one*). The tension forces caused by the strings are thus indexed through the linguistic determiner *this* combined with the embodied communicative multimodality— that is, Ian's pointing gesture point to the two *T*s marked on the display of the equilibrium system on Zac's Lab notebook (see Figure 23). Through their intertextual readings of the materials and the graphic display on Zac's Lab notebook, Ian's students, as less experienced physicists, are shown by their eye gaze in Figure 23 to be engaged in socialization activities to learn how different kinds of forces potentially affect the equilibrium status and system.

In line 12, by stating *that's eh most possible error you can have*, Ian concludes his readings and interpretations of the quantitative data results collected by the group of students. Perhaps, Ian is a little unsure if his students follow his instruction. Thus, in line 13, Ian self-initiates a new turn (Schegloff, Jefferson, & Sacks, 1977) to further engage his students in socialization activities, explaining that the weights of the mass objects would not lead to errors. Concurrently, in line 14, Ian uses his right index finger to point to the set of the central mass object on the experimental equipment (see Figure 24-1) when voicing the first prepositional adverb *here*, and then the set of the left-side mass objects on the experimental equipment (see Figure 24-2) when voicing the second prepositional adverb *here*. The Figures 24-1 and 24-2 also illustrate Ian's gestures and his students' eye gaze. The invisible forces of the mass objects that are referenced by the two referential expressions *here* are thus indexed through the embodied communicative multimodality (i.e. Ian's pointing gestures).

In lines 17 and 18, Ian further explains that the tension force caused by the string should equal the gravity, stressing the word *must*. Simultaneously, as shown in lines 19 and 20, Ian uses his right index finger to point to the string that holds the right-side mass object, and then his left index finger to point to the string that holds the left-side mass object (see Figures 25-1 and 25-2). In doing this, Ian visuospatially illustrates that the tension force caused by the string that holds the mass objects is equal to the natural gravity. In line 21, Zac voices the discourse marker *yeah* with a lower pitch, signaling his reception turn of information (Fuller, 2003). Then, in line 27, Ian concludes this socialization activity by uttering *So thing must happen like here*. When voicing the word *here*, in line 28, Ian uses his pencil to point to the left-side pulley and then the right-side pulley. In doing this, Ian creates a socialization space to teach his students how the present physics event (i.e. the friction force caused by pulleys) links to the prior event discussed at the beginning of the activity (that is, the force acting at an angle, such as $sin\ \theta$) (see Figures 26-1 and 26-2).

Excerpt 3 illustrates the application of multimodal resources of spatial repertoires to provide Ian and his undergraduate physics students a cognitive and spatial domain to conceptualize "mathematical participants and their relations (e.g., in terms of similarity, proximity in space and time)" (O'Halloran 2015, p. 70) permitting insights into the nature of the physics realities encoded symbolically. The use of symbolic conventions in the mathematical graphs and diagrams (e.g., x, y, and z axes) are disciplinarily situated visually and spatially in scientific ways. The use of multimodal resources of spatial repertoires also functions to provide interactional cues for linguistic repertoire and mathematical symbolic systems and as support to scientific reasoning with mental images (Kosslyn, Ganis, & Thompson, 2001).

4.1.3 Visualizing physics reasoning and mathematics through spatial repertoires

Meanings in physics discourse and instructional practices are not always indexed through natural languages but also through a list of physics constants and variables and their notations. An example is Albert Einstein's formula $E = mc^2$. Here, the physical symbols E, m, and c are not letters (or words) but physics notations that indexically suggest a disciplinary voice and membership. The mathematical symbolic signs and multimodal displays can complement the linguistic resources of spatial repertoires in physics discourses as members advance their knowledge and skills. These signs and graphic representations provide straightforward contextual information for scientific reasoning about physics relations (e.g., points, lines, two-dimensional planes, three-dimensional objects). Such use of visual multimodalities in instruction is evident in Excerpt 4 below, where Kelly and her students engage in a Newton's Second Law of Motion problem through their intertextual readings of the visual displays— the visual displays demonstrate energy and velocity acting on objects. To help her students understand the directions of varied forces, Kelly asks for one volunteer to draw a free-body diagram on the whiteboard to visualize different kinds of forces on objects and their directions. At the beginning of Excerpt 4, one student, Alex, volunteers to draw the free-body diagrams.

Excerpt 4: What about A?

[Classroom discourse transcript: Kelly, October 11, 2017]

1 Alex First, on the cart
2 [We don’t care about (.) >like< (.) the mass of the cart and gravity, right?
3 [*draws a downward arrow under the cart, and writes symbols* $m_c g$
4 Because it [doesn’t matter. It’s all that about, right?
5 [*draws an upward arrow above the cart, and writes symbol N*
6 *draws a leftward arrow next to the cart, and writes symbol T*

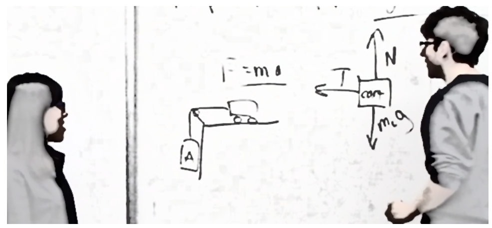


Figure 27

7 ↑Here you go, Kelly
8 Kelly→ <u>A</u>:=
9 Ss → =What about A
10 Alex What about A:?
11 *draws a downward arrow below object A, an upward arrow above it, and then a leftward arrow next to object A*

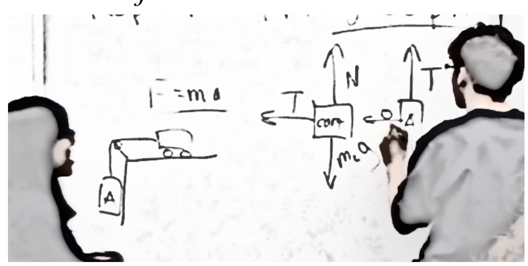


Figure 28

12 [Do you put something like this, like <zero>?
13 [*adds number zero above the leftward arrow*
14 Kelly→ [No, you don’t have to
15 [*grabs the marker back from Alex, erases the leftward arrow and number zero*

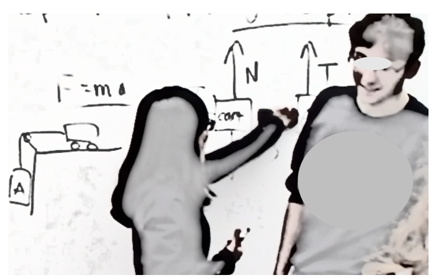


Figure 29

16 [°Go back°

17 [*moves her right thumb back and forth to show a go back to your seat gesture*
18 Mike There is no force (inaudible)
19 Alex I know. That's why I wrote zero
20 Mike Oh: ↑okay
21 Kelly ↓Okay. So you have <two> free-body diagram
22 And you know that the [cart didn't move
23 [*points to the cart diagram*
24 And in y axis
25 So, you know [m_c times *g* equals to *N*
26 [*writes the equation* $m_c g = N$

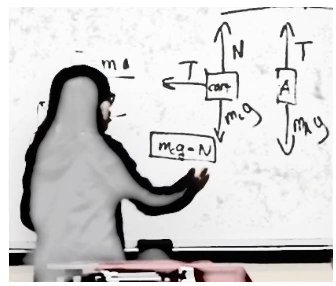


Figure 30

27 So, the [external force acting on the cart (0.2) [is tension
28 [*points to the symbol T*
29 [*points to symbol T*

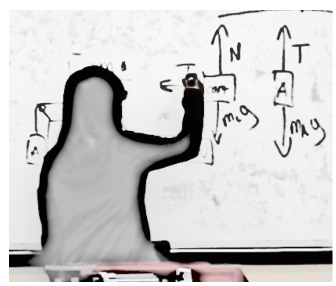


Figure 31

30 So, you [will know that *a*: direction of-
31 [*draws a leftward arrow above symbol T and writes symbol* a *above the arrow*

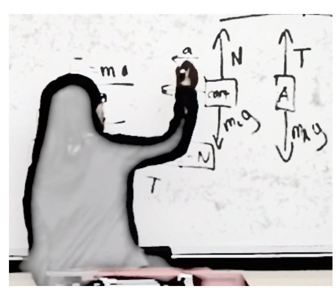


Figure 32

32 *a* direction should be [equal to-
33 [*points to the equation* $F = ma$

34 [Should be the same as [the direction of the tension
35 [*points to the equation* $F = ma$

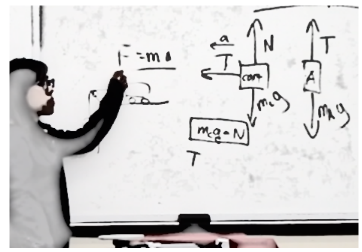


Figure 33

35 [*points to symbol T*

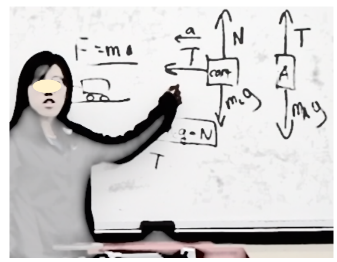


Figure 34

In Excerpt 4, in line 2, Alex tells Kelly and his peers that the gravity and mass of the object Cart can be ignored. Simultaneously, on the diagram, Alex marks the forces with physics notations (i.e. N, T, $m_c g$) and the force directions acting on the object Cart with arrows (as shown in lines 3, 5, and 6, as well as Figure 27). Here, Alex verbally names the forces (i.e. mass of the cart and gravity) but not their directions. Instead, as shown in Figure 27, he draws three arrows on the diagram to visually represent the directions of forces (i.e., upward, leftward, and downward arrows). When Alex works on the free-body diagrams, Kelly and the rest of the class eye-gaze at the graphic displays of the forces and their directions marked by him (see Figure 35 below). In lines 8 and 9, Kelly and some students ask *what about A*, noticing that Alex does not reference the forces and their directions acting on the object A. In lines 10 and 11, Alex repeats their question and draws arrows around the object A. However, it seems that Alex is unsure if any non-existing force should be marked, as he asks Kelly if he needs to put the number zero on the diagram to visually show non-existing force acting on the object A (line 12). Concurrently, while using the referential expression *like this like zero* in line 12, Alex writes the number zero above the leftward arrow that he draws earlier (see Figure 28).

Figure 35 exhibits Kelly's and students' eye-gaze at Alex's free-body diagrams.

In line 14, Kelly tells Alex that he does not have to write the number zero. At the same time, she grabs the marker back and erases the leftward arrow and number zero marked on the diagram (see Figure 29). Here, Kelly's embodied action of erasing the arrow and number previously marked by Alex works as corrective feedback on the errors that made by Alex on the free-body diagrams. That is, no value should be marked for non-existing forces. Number zero does not represent absence of value. Number zero represents a value between zero and the product of x. For this mathematical reasoning, Kelly erases the number zero marked by Alex. Alex may not know the mathematical reasoning explaining Kelly's action and simply transfer his knowledge of forces acting on the object cart to object A.

Kelly's embodied action of erasing the arrow and the number zero marked by Alex symbolically functions as support for other spatial repertoires by visuospatially complementing the physics instructional practices referencing a specific scientific event (Kosslyn, Ganis, & Thompson, 2001). That is, different from the object cart, there are only two forces acting on object A, including the upward force of tension (T) and downward gravitational force with a magnitude of object A ($m_A g$).

In line 18, on the way back to his seat, Alex is told by his peer Mike that no force exists in the direction he has indicated. Here, the peer feedback Mike gives is probably based on his physics understanding of forces and directions as well as his intertextual reading of Kelly's embodied action of erasing the arrow and number marked by Alex. Alex acknowledges Mike's comment by saying *that's why I wrote zero* in the subsequent turn. Unfortunately, Alex and Mike may not necessarily realize that non-existing force should not be marked with number zero on free-body diagrams.

Kelly continues her instruction. In lines 21 and 22, she tells the class that, based on the visual displays of forces and their directions, the cart does not move. Under this condition, natural force acting on the object cart equals the mass of the object cart times gravity (line 25), which is symbolically represented by the mathematical equation $m_c g = N$ on the whiteboard (see Figure 30). Following this physics reasoning, in line 27, Kelly tells her student the unknown variable acting on the object Cart is tension (external force). Simultaneously, she points to the symbol T marked on the free-body diagram (see Figure 31). Kelly then draws a leftward arrow above the symbol T on the free-body diagram and marks that arrow with the symbol a. This visual display symbolically demonstrates that the direction of tension is the same as that of acceleration acting on the object cart (see Figure 32). In the subsequent action, Kelly points to the equation $F = ma$, visually indicating that the physics reasoning about acceleration and tension is derived from Newton's Second Law of Motion $F = ma$ (see Figures 33 and 34).

Thus, Excerpt 4 demonstrates how in physics instructional practices, visual representations can provide international graduate assistants and undergraduates a simultaneous, cognitive and spatial space to conceptualize and link "mathematical participants and their relations (e.g., in terms of similarity, proximity in space and time), permitting insights in the nature of the physics realities encoded symbolically" (O'Halloran, 2015, p. 70). The use of symbolic conventions on the graphs and diagrams, such as the multimodal displays representing directions of varied forces, are disciplinarily situated visuospatially in scientific ways.

The joint use of multimodal resources of spatial repertoires and mathematical symbolic systems have been recognized as epistemic resources in understanding the problems presented in mathematics help-seeking sessions (Svahn & Bowden, 2019). Within physics socialization activities, experimental materials are frequently used with embodied communicative multimodalities (e.g. hand movements) for situated meaning-making in physics socialization activities. This is shown in Excerpt 5, where Ian responds to Zac's (Ian's student) question in a prior turn, concerning how the equilibrium status would change under the condition when the friction and tension forces are not equal. As he verbally explains the forces acting on an equilibrium system, Ian uses classroom experimental equipment (a meterstick, two pulleys, two table clamps, string and three mass sets) simultaneously with his hand gesture movements to visuospatially display how the directions of forces impact the equilibrium status between mass objects. Like Ian, Zac also utilizes these classroom materials concurrently with his hand gesture movements to show his understanding of the physics event being discussed.

Excerpt 5: Then the friction would go that way

[Classroom discourse transcript, Ian, November 1, 2017]

1 Ian That's a way to think
2 But if we are doing this
3 Like [adding this-
4 *[put his both index and middle fingers on the top of the right- and left-side mass objects*
5 [Instead of adding this mass, we are [adding these two sides at the same time
6 *[put his right index and middle fingers on the top of the central mass objects*
7 *[moves his both hands downward in front of the right- and left-side mass objects*
8 The friction should be [go other way, and [make this tension bigger
9 *[moves his both thumbs up slantwise*
10 *[moves his both index and middle fingers downward along the strings that hold the right- and left-side mass objects*

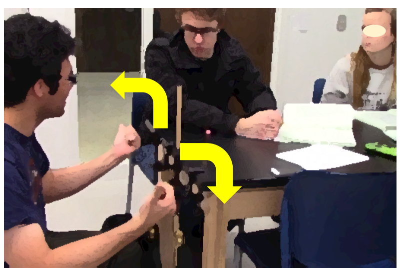


Figure 36-1

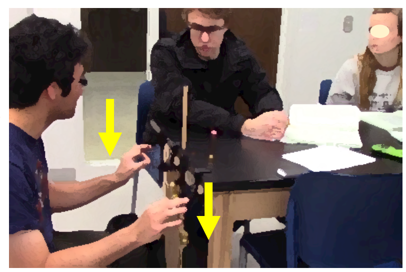


Figure 36-2

11 However, [this tension must be [the value of the gravity
12 *[moves his both thumbs and index fingers downward along the strings that hold the right- and left-side mass objects*
13 *[uses his both index fingers to point to the left-side mass objects*

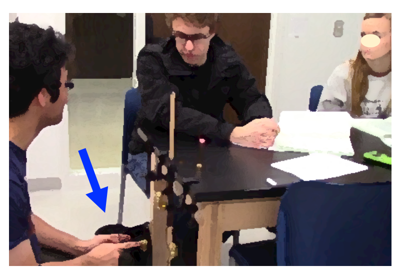


Figure 37

14 So, hard to tell that whether it is bigger or smaller
15 Zac ↓Okay

16 So, if (.) I add mass on both sides and [pull this

17 [*pulls the string that holds the left-side mass object downward a little*

18 Then, [the friction would go that way

19 [*moves his right index finger downward slantwise over the string that holds the left-side mass objects*

Figure 38 

20 And then-

21 Ian Tension should be smaller

In Excerpt 5, in line 1, Ian recognizes the Zac's question by saying *that's a way to think*. However, the equilibrium of forces is not merely about the volume change between mass objects. Directions of the forces (e.g. the force acting at an angle, such as $sin\theta$ or $cos\theta$) also influences the conditions for equilibrium. Thus, in lines 2 to 7, Ian hypothesizes a condition that if the weights of both the left- and right-side mass objects become heavier than the central mass object, the tension forces would also become heavier and go the opposite to the directions of movement. In line 8, as Ian utters *the friction should be go other way*, he also moves both his thumbs up slantwise to visuospatially demonstrate the opposite direction of movement the tension forces would go (see Figure 36-1). Due to this friction force change, the tension forces acting on both mass objects become heavier; simultaneously, Ian moves both his index and middle fingers downward along the strings that hold both the right- and left-side mass objects (see Figure 36-2). In doing this, Ian visually displays the opposing directions of movement that the equilibrium forces would go. In addition, the tension forces acting on both mass objects should equal to the value of gravity, so those forces can reach an equilibrium status. Under this physics condition, in line 11, Ian says *this tension must be the value of the gravity*. Concurrently, Ian moves both his thumbs and index fingers downward along the strings that hold the right- and left-side mass objects when saying the first part of the phrase *this tension must be*. Ian then uses his both index fingers to point to the left-side mass object when saying the second part of the sentence *the value of the gravity* (see Figure 37). In doing these gesture movements, Ian teaches the abstract physics concept— the tension forces that are caused by the strings and acting on both mass objects should be equal to the force of gravity.

In line 15, Zac's discourse marker *Okay* with a lower pitch functions as a reception turn (Fuller, 2003) in response to Ian's explanation. In the subsequent turn, Zac uses the discourse marker *so* to launch a new course of action (Bolden, 2006)— that is, in line 16, Zac hypothesizes a condition where if the weights of mass objects on both sides increase and the tension forces caused by the strings become heavier, the friction force caused by the pulleys would go in the opposite direction of the mass objects and strings. At the same time, he mentions these actions, Zac manipulates the objects and the string connecting those objects to illustrate them. In line 18, Zac says *the friction would go that way*. Simultaneously, Zac moves his right index finger downward slantwise over the string that holds the left-side mass object (see Figure 38). Here, the opposite direction of the friction force is indexed through both the linguistic determiner phrase *that way* and Zac's pointing movement over the materials (strings). In line 21, Ian says *tension should be smaller* to complete the phrase Zac's utterance in line 20. Ian's response is based on his intertextual reading of the visuospatial representations that Zac makes to represent the physics event being discussed. Here, a mutual understanding about tension forces and directions are built through the co-operation of Zac, who provides verbal talk simultaneously with the use of gestures moving over the materials (strings), and of Ian, who operates on that talk through his intertextual readings of Zac's embodied display over the materials (strings) (Goodwin, 2013).

Thus, Excerpt 5 exhibits that classroom materials for physics experiments can function as epistemic resources to provide straightforward contextualized information for physics reasoning about the symbolic formulations of physics and mathematics entities and relations (e.g. directions of different kinds of forces) (Lemke, 1998). The use of experimental materials thus helps "transport physical phenomena into the perceptual presence of physicists and also serve as a locus in which physicists and physical phenomena can be brought into physical and symbolic contact with one another" (Ochs et al., 1996, p. 350). Within the physics disciplines, the multimodal resources of spatial repertoires operate closely with mathematics symbolism to foreground and background physics processes in physics activities.

4.2 Discussion– Chronotopes of physics socialization activities

The findings laid out in Chapter 4 illustrates how meanings in physics instructional practices are constructed through the chronotopic (re)contextualization of previous physics reasoning and future applications in present activities about physics events. This chronotopic (re)contextualization is mediated through the 'spatiotemporal link' (Bakhtin, 1981) of disciplinary spatial repertoires and mathematical symbolism and images. The examination of the chronotopic nature of physics discursive practices is critical to understanding the dynamic multiplicity of physics instructional practices by international graduate assistants *in situ*.

4.2.1 Chronotopic link through disciplinary spatial repertoires and mathematics

The Bakhtinian (1981) dialogic construct of the chronotope highlights the sequential and simultaneous contributions to meaning making that are mediated through semiotic signs audible and visible to participants. Within the physics discipline, the chronotopic link through disciplinary spatial repertoires and mathematical symbolic systems creates a dialogic instructional space in which multilingual practices of knowledge construction can be achieved through multimodal resources of spatial repertoires. When physics reasoning cannot be constructed through linguistic and bilingual practices of the instruction, simultaneous use of embodied communicative multimodalities (e.g., gesture movements) or visual displays serves as a spatiotemporal link connecting translingual practices to physics reasoning. Here, this simultaneous chronotopic activity that links translingual resources of spatial repertoires to physics reasoning "accommodates the fact that selective words from different languages would find coherence for situated activities in combination with other nonverbal resources" (Canagarajah, 2018, p. 275). This simultaneous chronotopic activity also maintains the sequential chronotope in instruction to engage undergraduates in joint meaning making activities (Goodwin, 2018).

The intertextual network of simultaneous and sequential chronotopes helps accelerate scientific inquiry and error analysis, enabling translation of scientific thoughts into discourse (linguistic and textual) practices (Uttal & O'Doherty, 2008). In contrast to some social science disciplines (e.g., language teaching and learning), meaning making in physics instructional practices is not always indexed solely through the linguistic repertoires but through the incorporation of physics notations, mathematics equations, and the multimodal nature of spatial repertoires. For instance, visual representations are frequently used by international graduate assistants to work as an interactional link between linguistic repertoires and mathematical knowledge. Multimodal materials then become active resources for knowledge construction in physics instructional activity and are in constant dialogue with other resources of spatial repertoires. Progressively annotated graphic displays and the employment of disciplinary spatial repertoires establish a chronotopic intertextual network through which international graduate assistants and their undergraduate students dialogically negotiate physics meanings, simultaneously positioning themselves and each other and aligning with one another in an intersubjective space.

Within the physics discipline, the process of becoming a competent physicist entails understandings of academic contexts and accommodations to disciplinary ideologies concerning how discourse and material resources can be used to acquire and express epistemic stances (Duff, 2010). In this study, when less experienced physicists (undergraduate students) lacked full command of the academic registers to more fully contribute to the intersubjective knowledge, the use of multimodal resources of spatial repertoires as epistemic support helped create a socialization space to move the teaching-learning activity forward and facilitate the socialization process. Experimental or laboratory equipment as epistemic resources in physics communication provided insight into how disciplinary discourse practices were situated in the holistic contexts of everyday routines, and how academic registers were not in isolation from materials resources in meaning making in physics socialization activities.

4.2.2 A spatial repertoire-informed chronotopic turn in instructional practices in physics

The physics discourse and instructional practices that are mediated through the integration of disciplinary spatial repertoires and mathematical symbolic system reflect not only the synchronic juxtaposition of discursive practices related to multiple physical spaces, but also the diachronic dimension in which present actions link back to prior logical reasoning and forward to future applications. The simultaneous and sequential engagement in physics instructional activities facilitates and is shaped by the weaving of intertextual network across the confluence of verbal descriptions, multimodalities, and mathematical symbolic systems. The present study suggests a spatial repertoire-informed chronotopic *turn* in analyzing sciences discursive and instructional activities across time and space. Thus, we would more thoroughly understand the chronotopes of scientific communication in which scientists participate in collaborative interpretative activities, journey through their disciplinary spatial repertoires, and transport themselves into the constructed visuospatial representations and physics/mathematical reasoning of scientific phenomena.

Chapter 5

Competing discourses of expertise in physics socialization activities

In the case of language socialization, multiple, competing, and dynamic social structures are variably oriented to and made relevant within fields of activity by expert and novice social actors, who (re)create, resist, or transform them.

Howard (2012. p. 343)

The Bakhtinian (1981) heteroglossic approach not only implies acknowledgement of the presence of different languages and codes (raznojazyčie) as a resource, but also entails a commitment to multidiscursivity (raznogolosie) and multivoicedness (raznorečie).

Busch (2014, p. 37)

Chapter 5 answers Research Question 1 and sub question 1(b) through an examination of the challenges related to disciplinary discourse and ideological practices that bi/multilingual international graduate assistants encountered in their socialization activities with their undergraduate physics students. This chapter also addresses how focal physics international graduate assistant participants and their undergraduate students engaged with those challenges to facilitate the socialization processes in physics contexts.

In this chapter, I apply Bakhtin's (1981) construct of 'heteroglossia' (particularly, its relation to indexicality, tension, and multivoicedness) to examine how disciplinary expertise and discourse practices are constructed through the integration of spatial repertoires and mathematical symbolic systems between bilingual physics international graduate assistants and their undergraduate students. It also addresses how increased competing interactions among undergraduate physics students in international graduate assistant-led learning contexts create spaces for peer language socialization. For this research, multimodally-mediated socialization activities between focal physics international graduate assistants and their undergraduate students were video recorded. Data were analyzed through combining the method of multimodal conversation analysis with Bakhtin's construct of heteroglossia. Findings reveal that during some international graduate assistant-led instructional activities, the international graduate assistants paused in conversation due to differences in the discursive registers previously learned by international graduate assistants versus their undergraduate students in their primary physics education. Some of these activities are due to differences between Mandarin Chinese and English spatiotemporal expressions. Findings also show that more experienced undergraduate physics students took the conversational floor to create spaces for peer language socialization and compete with each other for disciplinary expertise. These competing discourse practices and voices among undergraduates could been seen as momentarily decentering the international graduate assistants' position as course instructors, even though the undergraduates' performances would ultimately be evaluated by international graduate assistants through their readings of the physics events being discussed. Such findings suggest that the heteroglossic nature of physics socialization activities is a combined demonstration of physicists' spatial repertoires and knowledge of physics concepts, and their human experiences and engagement in physics and mathematics.

5.1 Heteroglossic practices in physics socialization activities

The findings in this section demonstrate the heteroglossic nature of competing discourses of disciplinary expertise, as mediated through the chronotopic (re)contextualization of disciplinary spatial repertoires and mathematical symbolic systems in physics socialization activities. I present a multimodal conversation analysis of the interaction data to show how bilingual international graduate assistants and their undergraduate physics students, who are relatively more and less experienced members of the physics discourse community, use their pre-existing heteroglossic voices and discourses to shape their participation in physics socialization activities as relatively less or more experienced members. The analysis also addresses how increased competing interactions among undergraduate physics students in international graduate assistant-led learning spaces create contexts for peer language socialization.

5.1.1 Competing discourses of expertise through spatial repertoires and mathematics

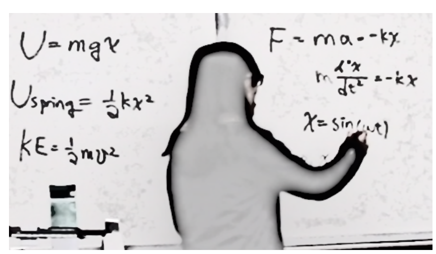
Within the physics discipline, critical to the construction of disciplinary knowledge and expertise involves the competence of appropriately (re)contextualizing physics socialization activities mediated through the confluence of disciplinary spatial repertoires and mathematical symbolic systems. Physicists frequently (re)contextualize their prior logical reasoning and anticipated future applications in order to understand the new meanings that become salient in current discussion about a physics event or entity. Meanings in physics communication are not always indexed through human languages, but often through a sequence of physics constants and variables and their notations, such as Albert Einstein's formula $E = mc^2$. Here, the physical symbols E, m, and c are not letters (or words) but physics notations, the use of which indexically suggests a disciplinary voice and membership in the physics discipline. Like learning a new language, it takes time and continuous practices for undergraduate physics students to become familiar with those symbols and equations as well as their notations and pronunciations. When undergraduates lack full knowledge of physics symbols, equations, notations and pronunciations, they can supplement their understanding through the use of communicative multimodalities (e.g., pointing gestures). This finding is illustrated in Excerpt 1 below, where Kelly teaches the class the mathematical relationship between the equations $x = sin\ (\omega t)$ and $m\frac{d^2x}{dt^2} = \ -kx$ in the calculation process. In line 4, one undergraduate student, David, tries to ask Kelly if the physics symbol ω refers to the construct of angular velocity. But he does not know how the name of that symbol (see Transcription Conventions in Appendix)

Excerpt 1: That /dʌblju/ is angular velocity?

[Classroom discourse transcript: Kelly, October 18, 2017]

1	Kelly	So, we want to plot in [<this function> into the [differential equation
2		[*points to the equation* $x = sin\ (\omega t)$ with *the back of her left hand*
3		[*points to the equation* $m\frac{d^2x}{dt^2} = \ -kx$ *with the back of her left hand*
4	David→	>That- that- that< /dʌblju/ is angular velocity?
5	Kelly →	↓Yes. [<u>Omega</u>
6		[*points to the physics notation* ω on the board with the marker

Figure 39



In Excerpt 1, line 1, to index the mathematical relationship between function $x = sin\ (wt)$ and differential equation $m\frac{d^2x}{dt^2} = -kx$, both of which she has written on the whiteboard, Kelly says *we want to plot in this function into the differential equation*.

Here, Kelly (as a more experienced physicist) uses the first-person plural pronoun *we* to position her undergraduate physics students (as less experienced physicists) as practitioners in the current activity about the physics event being discussed. As she speaks, in lines 2 and 3, Kelly uses the back of her left hand to point to the equation $x = sin\ (\omega t)$ and then the equation $m\frac{d^2x}{dt^2} = -kx$ written on the board. In doing this, Kelly visually shows her undergraduates how these two equations are derived as well as their mathematical relationship are related to one another in the calculation process.

In line 4, David asks Kelly if the symbol ω stands for the angular velocity in the equation, but he calls the symbol /dʌblju/ instead of omega (/omɛgə/), the symbol's name in physics. David's lack of full knowledge of the name of the physics notation ω does not lead to a communication breakdown with his instructor and peers. In line 5, Kelly responds to David with an affirmative expression *yes* and gives the name of the physics notation ω (omega /omɛgə/). Simultaneously, Kelly points to the physics notation ω with the marker to show that she understands David's question and to recast his error with the correct term (see Figure 39). The communication is achieved potentially because the physics notation ω in the mathematical equation $x = sin(\omega t)$ written on the whiteboard provides both the graduate assistant and undergraduate students with a cognitive and spatial domain where David's question can be (re)grounded and recast with the related mathematical symbol (i.e. physics notation ω) and its relation to other physics quantities in the discussed mathematical equation (Uttal & O'Doherty, 2008).

Mathematics knowledge and communicative multimodalities can complement the linguistic forms and functions in physics socialization activities as members advance their knowledge and skills. However, in activities where international graduate assistants lack knowledge of implicit communication cues signaled by the target language, student questions may not be addressed and answered effectively. The international graduate assistants' relative unfamiliarity with the pragmatics of the English language can pose a considerable challenge to their ability to perform their roles as competent physicists and graduate instructors (Chiang, 2016). This is shown in Excerpt 2 below, where Kelly teaches the class how to solve a physics problem concerning the angular velocity related to forces and motions by using derivatives of $sine$ and $cosine$ in mathematical equations.

Excerpt 2: Have you learned about the derivatives of $sine$ or $cosine$?[10]

[Classroom discourse transcript: Kelly, October 18, 2017]

6	Kelly		So: [we try to plot in-
7			[*faces the whiteboard*
8		→	[↑Have you learned about <the derivatives> of *sine* or *cosine*?
9			[*turns to face her students*
10	Ss	→	↓Yes
11	Kelly		>Oh, good<
12			So: [*writes the left part of the equation* $\frac{d^2x}{dt^2} =$
13	David	→	[I hope so
14	Ss		☺☺
15	Kelly		[So: you will write
16			[*writes the right part of the equation* $\frac{d^2x}{dt^2} = -\,\omega^2 sin\,(\omega t)$
17	Eason		[(inaudible) °second derivative is just negative° (inaudible)
18	Kelly		*turns to face her students and points to the equation with her left hand*
19			Is that okay for all of you?
20	Alex	→	Kelly (inaudible)-
21	Eason	→	[The first derivative [is $sine$, $cosine$, >the first derivative,< $cosine$, negative $sine$

[10] Please note that Excerpt 2 includes at least two turn construction units, including one between Kelly and the class, another one between Kelly and Alex, and the other one between David and Eason. These three units are marked with arrows highlighted by the colors green, orange, and blue.

22 [*visuospatially demonstrate trigonometric function with his left index finger*

Figure 40

23 Alex → [We don't know=
24 Kelly → [=Oh, I set y as the initial condition
25 Eason→ [And the second derivative is $cosine$, negative $sine$=
26 [*uses his left index finger to visuospatially demonstrate* $cosine$ *trigonometric function*
27 Alex [(inaudible)
28 Kelly You mean [this one?
29 [*points to the equation* $x = sin\ (\omega t)$ *with her left hand*
30 ↑Oh ↓yeah
31 *adds A to the equation* $x = sin\ (\omega t)$, *so it becomes* $x = Asin\ (\omega t)$
32 David→ = I didn't know that, >whatever<
33 I never do that

In line 8, Kelly asks her undergraduate students if they have learned the derivatives of $sine$ and $cosine$ from their prior STEM education. Based on her students' positive response (line 9), Kelly continues her instruction at full throttle. She writes the first derivative equation $\frac{d^2x}{dt^2} = -\ \omega^2 sin\ (\omega t)$ on the board (lines 12 and 16). However, not all of her students are familiar with the derivatives of $sine$ and $cosine$ functions. In line 13, one student, David, says *I hope so*, which suggests he may be uncertain about what the derivative equations of $sine$ and $cosine$ are. His utterance could also be an attempt at humor (Bucholtz et al., 2011) to mitigate the uneasy moment experienced by his peers who lack knowledge of the derivatives of trigonometric functions. In line 14, some of his peers laugh, which may indicate a solidarity with David (and his attempt at humor) and possible uneasiness if they are also unsure about the derivatives of $sine$ and $cosine$.

Kelly does not seem to recognize the pragmatic cue(s) signaled by David's phrase *I hope so*. She seems unaware that some of her students lack the knowledge of the derivatives of trigonometric functions and writes two equations on the board. In line 19, Kelly turns from the board and does a comprehension check, asking the class *Is that okay for all of you*? In the next turn, line 20, and continuing in line 23, Alex responds to Kelly by saying the phrase *we don't know*. Alex is trying to tell Kelly that he and others in fact lack some knowledge of the derivatives of $sine$ and $consine$. Overlapping with Alex, in lines 21 and 25, Eason responds to David's earlier utterance in line 13, thus creating a second conversational space within Kelly's instructional space for peer language exchange and socialization. In that second space, in lines 21 and 25, Eason looks at David and says what the derivatives of $sine$ and $cosine$ functions are, while simultaneously moving his left index finger in the air to visuospatially demonstrate the derivatives of $sine$ and $cosine$ functions in trigonometry (lines 22 and 26) (see Figure 40).

Here, two conversational spaces are created within the Kelly-led learning context. In the first conversational space, lines 20 and 23, Alex says *we don't know* (line 23), though he is interrupted by Kelly before he can indicate what isn't known. In the second conversational space, lines 21 and 22, Eason overlaps with the first conversational space between Alex and his instructor Kelly by verbally naming and gesturing at what the derivatives of $sine$ and $cosine$ functions are for the benefit of his peers who struggle with those functions, something possibly also signaled in Alex's *we don't know* in line 23.

Let's take a closer look at the two conversation spaces within Kelly's instructional context. In the first conversational space, in line 24, Alex is interrupted by his instructor Kelly, who says *Oh I set* y *as the initial condition*, possibly assuming that what her students struggle with is y-axis in the mathematical equations on the board. Kelly may be responding to Alex's indication of unspecified lack of knowledge in line 23 by explaining in line 24 the logical reasoning for the calculation process— that is, the y-axis is already set as an initial condition.

In the second conversational space, Eason verbally explains what the derivatives of $sine$ and $cosine$ functions are to David and others who struggle with the functions. The derivatives of $sine$ and $cosine$ functions in trigonometry are visuospatially mediated and indexed through Eason's gesture movements (see Figure 41 for a visual display of trigonometric functions). Although Eason's gesture movements for the derivatives of $sine$ and $cosine$ look similar, he also verbally names the differences— that is, the first derivative is $sin\ (x) = cos\ (x)$ while the second derivative is $cos(s) = -sin(x)$ (see Figures 42-1 and 42-2 below for detailed visual representations of Eason's gesture movements). Through his intertextual reading of Eason's gesture movements, David is made aware of his prior lack of knowledge about the derivatives of trigonometric functions. He says *I didn't know that* (line 32) and *I never do that* (line 33). Here, the demonstrative determiner *that* refers to the disciplinary knowledge about the derivatives of trigonometry functions required to solve the physics problem being discussed.

Figure 41 visually demonstrates the trigonometric functions.

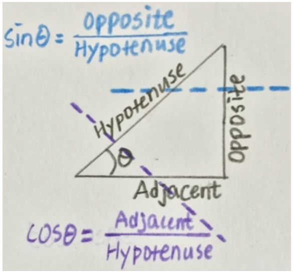


Figure 42-1 and 42-2 illustrate how Eason gestures the derivatives of *sine* and *cosine* function in trigonometry.

Figure 42-1

Figure 42-2

Analysis of the data in Excerpts 1 and 2 show that physics socialization can still occur when less experienced physicists (i.e. undergraduate students) lack full command of disciplinary knowledge required for physics problem-solving activities. Within the physics discipline, when physics meanings cannot be communicated through linguistic resources, the mathematic symbolic systems and/or communicative multimodalities provide physicists with a rich cognitive and spatial domain in which to (re)contextualize "mathematical participants and their relations (e.g., in terms of similarity, proximity in space and time)" (O'Halloran, 2015, p. 70), permitting insights into the nature of the physical realities encoded symbolically. The heteroglossic nature of such physics discourse practices creates a multivoiced space for less experienced physicists (students David, Eason, and Alex) to teach each other and demonstrate their inexpertise compared to Kelly at the same time that their participation in the conversation likely construct them as more expert than their non-verbal peers. Thus, rather than being excluded or marginalized from the learning opportunities, these students participate actively. Their participation in the conversation when Kelly does not recognize the pragmatic messages signaled by David's phrase *I hope so*, imperfect socialization (He, 2016) may occur in which Kelly's expertise is decentered creating a space for student Eason to step in and exhibit his expertise.

Socialization activities in academic contexts involve asymmetric knowledge and power relations that position instructors as experts and students as apprentices (Duff, 2012). Bakhtin's (1981) construct of heteroglossia allows us to see when tension can be reflected in the competing discourses that arise from the multiplicity of disciplinary voices. Within the physics discipline, the heteroglossia of competing discourses and voices can occur in situations like that illustrated in Excerpt 3 below, when the international graduate assistant participant (Kelly) pauses in instruction for extra time to rephrase a challenging physics concept and when more experienced undergraduate physics students take the conversational floor to create a space for peer language socialization within the graduate assistant's instructional contexts. In Excerpt 3, one undergraduate student, David, asks Kelly for further information on the kinetic energy of friction and acceleration and their directions acting on an object. Forces and their directions can be challenging for novice physics students because they are invisible in our physical world. Excerpt 3 below presents how sometimes language may not be a powerful enough resource to express those invisible physical realities, verbally or in writing, particularly when the language of instruction is native to some participants and not to others.

Excerpt 3: It depends on which direction[11]

[Classroom discourse transcript: Kelly, October 11, 2017]

1	David	So like, if we have friction involved
2	Kelly	Yes
3	David	And so like-
4		If you're given a cart and <push> in one direction
5	Kelly	Yes
6	David	Hmm (.) so like-
7	→	Can friction like- actually add to the acceleration
8	Kelly →	You have to add (.) if you (0.2) if (.) [friction
9	David	[>So like< a cart is pushed the opposite=
10	Kelly	=Way?
11	Brian	Yeah, it would, it would
12		[(inaudible)
13	David	[Well
14		It's not the mass string does the push
15		But like, I don't understand about
16		(.) a friction was [(inaudible) slows down
17	Eason	['Cause friction <holds the motion>
18	Kevin	'Cause it slows down in that [direction
19	Brian→	[It depends on which direction=
20	Kelly→	[=↓Yes
21	David	[So then, it's kind of (inaudible)
22		It should be speeding
23	(0.6)	
24	Kevin	Or it's accelerating [in that direction, [but=
25	Brian	[Like [If it's
26	Kevin→	= >it feels like< it decelerates in that direction=
27	Brian	If (.) its deceleration is like (0.4) <decelerating> the object=
28	Kelly→	=↓Yeah
29	Brian	And the friction eh assists the acceleration
30	Kelly	It should be opposite to the motion- the direction of the motion
31		↓Yes
32		So, if you [push that way,
33		[*waves her left hand to show a motion towards left direction*

[11] Please note that in Excerpt 3, the turn construction units between David and Kelly, Brain and Kelly, and Kevin and Kelly are marked with arrows highlighted by the colors green, orange, and black.

34

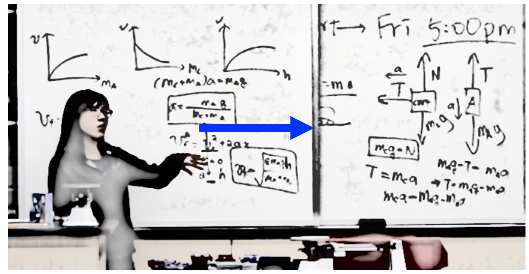


Figure 43

35 your [friction will be this way
36 [waves her right hand to show a motion towards right direction

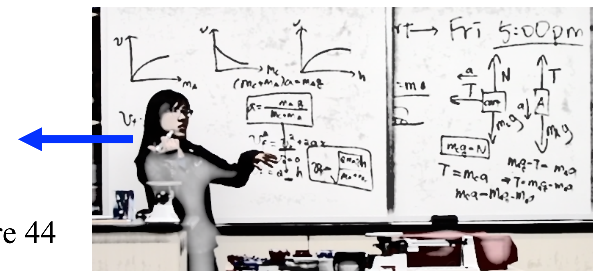


Figure 44

37 David→ ↓Yeah
38 Kelly ↓Yeah

As stated above, Excerpt 3 is initiated by a question David has just asked Kelly about the kinetic energy of friction and acceleration and their directions acting on an object. In lines 1-7, David rephrases his question in order to make it focus on the relationship between kinetic forces of friction and acceleration acting on the object cart. Perhaps David wonders how the force of friction slows down an object because that force is invisible, though many invisible physical realities can be visualized and contextualized through visuospatial representations. However, in line 7, when David asks *Can friction like- actually add to the acceleration*, the verb phrase *add to the acceleration* seems to confuse Kelly and possibly some other students. In order to understand the problem with this choice of verbs, we need to know the relationship between friction and acceleration. In physics, friction forces are independent of speed (acceleration forces). When a push is made to move an object on the surface, static friction slowly ‘increases’ to a maximum value which ‘slows down’ the acceleration acting on that moving object. Now, let’s look again at David’s verb phrase *add to the acceleration*. I argue that David may be misusing the verb *add* in his utterance because friction and acceleration are acting in opposite directions.

Now, let’s look at Kelly’s response. In line 8, there are two micro-pauses in her utterance *You have to add (.) if you (0.2) if (.) friction*; those micro-pauses may allow Kelly extra time to process her thoughts and also to self-repair (Schegloff et al., 1977) her response to David’s question. David then rephrases his question differently *a cart is pushed in opposite* (line 9), which is completed by Kelly’s word *ways* with a rising intonation (line 10). There is no discernible pause between David and Kelly, probably because Kelly picks up on the word *opposite* in David’s utterance (line 9). The word *opposite* matches Kelly’s understanding of the kinetic energy of friction and the opposing direction of acceleration on an object.

When Kelly pauses in conversation for extra time to process her thoughts and rephrase her responses, beginning in line 11, a few more experienced undergraduates take the conversational floor and create a peer socialization space to demonstrate their disciplinary competence in teaching each other. In line 17, Eason says *‘cause friction holds the motion*; in line 18, Kevin says ‘*cause it [friction] slows down in that direction*; and in line 19, Brian states *it depends on which direction*. While her students are co-constructing their disciplinary knowledge in these lines, Kelly keeps silent. The students’ competing turns can be seen as temporarily decentering Kelly’s disciplinary position as the course instructor and the more experienced physicist. However, Kelly is not fully absent in the classroom interaction. In line 20, she joins the student peer socialization activity by giving a confirmation marker *yes* to affirm the students' utterances (lines 11-19) that matches her understanding of physics. There is no observable pause between Brian's assertion *it depends on which direction* (line 19) and Kelly's *yes* (line 20), probably because Kelly agrees with the key word *direction* in Brian's utterance. A similar example occurs in line 28 where Kelly says *yeah* to both Kevin's and Brian's immediately preceding turns (lines 26 and 27). There are no observable pauses between Kevin (line 26), Brian (line 27), and Kelly (line 28). This signals collaborative co-construction of the. Content, and may occur because Kelly hears the key word *direction* in Kevin's and *decelerating* in Brian's sentences. Those key words *direction* and *decelerate* match Kelly's understanding of kinetic energy of friction and acceleration and their opposing directions acting on an object. Within the physics discipline, friction and acceleration are in opposite directions.

Now, let's consider the particular key words— the noun *direction* and the verb *decelerate*. As the students' contributions end in 29, in lines 30 to 37, Kelly takes back the conversational floor, using her communicative multimodalities to illustrate the relationship between friction and acceleration. In line 30, she says *it [friction] should be opposite to the direction of the motion*. Kelly continues in line 32: *So, if you push this way*, and simultaneously, she gestures to demonstrate the opposite directions of friction and acceleration acting on a moving object with her hand movements (see Figures 43 and 44). Through their intertextual reading of her hand movements, students should understand that the direction of motion (acceleration) is positive, the direction of friction would be negative. A force acting in a negative direction would 'slow down' the force acting in a positive direction. This is probably why earlier in line 28, Kelly responds with a confirmation marker *yes* to both Kevin's word *direction* and Brain's word *decelerate*. The heteroglossia of competing discourses and voices among undergraduates documented in Excerpt 4 are evaluated by their instructor Kelly through her disciplinary competence.

There is another way to interpret Kelly's pause in instruction (line 8) that initiates the subsequent peer language socialization among her more and less experienced undergraduate physics students. I do not think Kelly's pause is a result of struggles with Chinese-English translation. Doing so may prevent us from recognizing the dynamic multiplicity of physics instructional practices by bi/multilingual international graduate assistants. After numerous readings of Excerpt 3 and the whole classroom discourse transcript from the day it occurred, I have wondered and struggled with whether Kelly's pauses in instruction, potentially, may result from metaphoric differences of spatiotemporal expressions between Mandarin Chinese and English language systems. Neuroscientists have claimed that the ways Mandarin speakers and English speakers approach spatiotemporal concepts are different (e.g., Boroditsky, 2001, 2018; Majid, Gaby, & Boroditsky, 2013). While English predominantly treats time as if it were horizontal change, Mandarin commonly treats time as moving both vertical (up/down) and horizontal (front/back). In other words, time and space are closely tied together as being directional both horizontally and vertically in the spatiotemporal expressions in Mandarin Chinese system. In contract, time and space are connected together as being directional horizontally in the spatiotemporal expressions in English system. In addition, English is a verb-driven language, but Mandarin is not. Possibly, Kelly's students voiced their struggles with acceleration and friction in physics using verbs (i.e. *ac*celerate vs. *de*celerate), while Kelly might not recognize such different spatiotemporal expressions being used in the English language systems, and may have been waiting for a spatial expression more similar to one used in Mandarin Chinese (i.e. expressing directions of acceleration and friction acting on an object) from her students.

5.1.2 Constructing disciplinary voice: Mathematics anxiety

The process of becoming a competent physicist in scientific disciplines entails socialization into the disciplinary knowledge and accommodation to the target cultural group's institutional and sociopolitical ideologies about linguistic and multimodal semiotic resources. These *id*eologies— *identity* and *ideas* (Woolard & Schieffelin, 1994) that reflect and are shaped by socialization at the local level and institutional structures at the societal level— can be explicitly defined or implicitly indexed through the heteroglossic nature of physics discourse practices. One such *id*eology observed in my research data is a set of beliefs about mathematics anxiety. In their graduate instructor practicum program, all of my focal international graduate assistant participants were made aware of the mathematics anxiety that many U.S. undergraduate students experience in sciences fields. International graduate assistants were advised to maintain a positive manner in order to help alleviate their mathematics anxiety while concurrently motivating their students to take another try. This can be seen in Excerpt 4, where Kelly keeps smiling when answering her students about their questions regarding the concept of the derivatives of $sine$ and $cosine$ functions being derived from mathematics (trigonometry). Some of her students sound surprised when they learn about this mathematics concept's connection to their physics problem. As some peers express their mathematics anxiety, other students offer support.

Excerpt 4: Oh: math is crazy[12]

[Classroom discourse transcript: Kelly, October 18, 2017]

34	Kelly	A. Is that okay?
35		*points to A in the equation* $x = A\sin(\omega t)$ *with her left hand*

Figure 45

36	Alex	↓Yeah
37	Kelly	Amplitude
38	David	Is it- is it (.) A: are maximum?
39	Kelly	↓Yes. [This is the amplitude of the: (0.2) position
40		[*points to A in the equation* $x = A\sin(\omega t)$ *with her left hand*
41	(1.0)	
42	Brian →	Where'd that- where'd that come from?
43	Kelly	[This one, this from?
44		[*points to* $x = A\sin(\omega t)$
45	→	[↓Yeah: <math>
46		[*opens her arms*

Figure 46

47		[*looks at the class and smiles to her students*

[12] Please note that in Excerpt 4, the turn construction units between Brian and Kelly as well as Alex and Brian are marked with arrows highlighted by the colors orange and blue.

Figure 47

48 Ss [☺☺
49 Kelly So:
50 Brian → .hh It came from math?
51 Kelly → Is that okay?
52 For all of you?
53 Alex → [↑Oh: this is crazy
54 [*scratches his head*

Figure 48

55 Kelly So, you have [this
56 [*points to* $\frac{d^2x}{dt^2} = -\omega sin\ (\omega t)$
57 Brian → <u>Don't</u> worry=
58 Kelly → =I know
59 So, you have [this equation
60 [*points to* $\frac{d^2x}{dt^2} = -\omega sin\ (\omega t)$
61 You [plot in
62 [*points to* $m\frac{d^2x}{dt^2} = -kx$
63 So *writes the equation* $-m\omega^2 Asin\ (\omega t) = -kAsin\ (\omega t)$
64 So, we can cancel [*A* and [*sine*
65 [*crosses out the symbols A*
66 [*crosses out the two sine*
67 Right?
68 (0.4)
69 Kelly So you can get the relations between [k, m, and ω, m
70 [*points to the symbols* k, ω, *and* m
71 Alex You can cancel <u>that</u> negative sign too, Kelly
72 Kelly ↓Yeah, I know
73 Ss ☺[☺
74 [*clap*

In Excerpt 4, in line 34, Kelly refers to the physics symbol A (amplitude) in an equation on the board, asking *is that okay* with a rising intonation. Concurrently, in order to visualize the relation between the physics symbol A and other physics quantities in the mathematical equation, in line 35, Kelly points to the physics symbol A in the equation $x = Asin(\omega t)$ with the back of her left hand (see Figure 45). Here, the referential expression *that* potentially refers to either the entire new equation $x = Asin(\omega t)$ or the physics symbol A (amplitude). In line 39, Kelly then tells the class that the physics symbol *A* refers to the amplitude of a position, she simultaneously points to with her left hand (line 40).

After a one-second pause, in line 42, a student, Brian, asks *what'd that come from*. Here, Brian uses the referential expression *that* to refer to the new equation $x = Asin(\omega t)$ Kelly had written on the board. Brian's use of the demonstrative determiner *that* may suggest that his disciplinary knowledge of trigonometric functions is insufficient to refer to the new equation by name. In line 43, Kelly responds with the phrase *this one, this from* with a rising tone while pointing to the equation $x = Asin(\omega t)$ with her left hand to visually show her understanding of the referent in Brian's question. In line 45, Kelly continues with the word *yeah* in a falling tone and another word *math* with a slowed speech rate. Concurrently, she opens her arms, looks at her students, and smiles at them (Figures 46 and 47). In line 48, her students then laugh in response to the Kelly. In her response, Kelly may smile at the class because she wants to alleviate student mathematics anxiety. She does this probably because she notices that the derivatives of trigonometric functions are challenging to some undergraduate students. Her students' collective laughter may help them mitigate the seriousness of physics lessons (i.e. the application of mathematics in physics problem-solving activities) by asserting the humorous aspect of mathematics learning (Roth et al., 2011). The undergraduates' collective laughter may also serve as carnivalesque ambivalence that opposes the serious side of physics/mathematics learning (Bakhtin, 1981).

The students' collective laughter does not end when Kelly initiates a new turn to complete her instruction (line 49). But in line 50, Brian interrupts Kelly's teaching and extends this collective laughter, saying *it came from math* with a surprised voice. Possibly as a way to recognize some undergraduates' mathematics anxiety in this moment, in lines 51 and 52, Kelly asks the class for any questions. In line 53, Alex responds to Kelly by prolonging the discourse marker *oh* with a rising tone and saying *this is crazy*. Here, the referential expression *this* can refer to all the mathematical procedures related to this physics event. Alex's utterance *this is crazy* potentially illustrates how complex such mathematical procedures are for him and some of his peers, especially those who have no prior knowledge about the derivatives of $sine$ and $cosine$. Brian picks up that pragmatic message concerning the mathematics anxiety experienced by Alex. In line 57, Brian says *don't worry*, as a possible recognition of his peer's mathematics anxiety and to try to motivate his classmates to stay engaged in the socialization activity. However, Alex's *this is crazy* can be framed as a speech act that is a cry for help that flies under Kelly's radar, and thus Alex's need for further instruction in the derivatives of $sine$ and $cosine$ goes ignored.

In the subsequent interaction shown in Excerpt 3, Kelly may not recognize the hidden pragmatic messages signaled by Alex's utterance *this is crazy* (line 53). Kelly continues her instruction by showing to the class how to plot the equation $\frac{d^2x}{dt^2} = -\,\omega sin(\omega t)$ into another equation $m\frac{d^2x}{dt^2} = -kx$ (lines 58-70). Kelly shows to the class how to plot the equation $\frac{d^2x}{dt^2} = -\,\omega sin\,(\omega t)$ into the equation $m\frac{d^2x}{dt^2} = \;-kx$. A new equation $-m\omega^2 Asin\,(\omega t) = -kAsin\,(\omega t)$ is then generated. Kelly tells her students that the same physics quantities in both sides of the equation can be cancelled. While Kelly is teaching this mathematical process, the class keeps silent possibly because most of the students have no prior knowledge about the derivatives of trigonometry functions. But there is further carnival play among her undergraduate students at the end of the physics problem-solving activity. The class remains silent until, in line 71, Alex reminds Kelly while she is summing up instruction on the mathematical process that she can cancel the negative signs on both sides of the equation. The class laughs and some students event clap; probably this is because they have finally made some contribution to the class problem-solving activity, even though they understand that the cancellation of negative signs matters nothing to the mathematical process. This collective laughter and applause may potentially function as carnival play (Bakhtin, 1981) in that undergraduate physics students are mocking their own lack of full disciplinary expertise and their incompetent participation in classroom problem-solving activities.

5.2 Disciplinary ideology and agency in physics instruction

Section 6.2 presents findings on the role of the disciplinary ideology and mathematical ageny in physcis instructional interactions that reflects a centripetal-centrifugal tension between the focal physics international graduate assistant participants and institutionalized ideological form of knowledge construction within physics community. The data show how institutionalized ideologies that regulate the contextual use of spatial repertoires and mathematical symbolic systems can shape how international graduate assistants (as more experienced members) model things in instruction, and how they engage undergraduate physics students (as less experienced members) to participate in socialization activities. The ideologies that are indexed through the use of linguistic, multimodal, and mathematical symbolic systems represent "the co-existence of socio-ideological constructions between the present and past, between differing epochs of the past, between different socio-ideological groups in the present, between tendencies, schools and so forth, all given a bodily form" (Bakhtin, 1981, p. 291).

As shown in Chapter 3, in the CSE Practicum program, CSE international graduate assistants were socialized into a number of classroom discourse practices and cultural expectations related to STEM instruction in U.S. higher education. One such practice was the I-R-E (initiation-response-evaluation) instructional sequence. During the instructional activities where their undergraduate CSE students were unable to fully answer instructor questions, CSE international graduate assistants were advised to respond with positive feedback to student incorrect answers in order to help alleviate student anxiety about mathematics and science. For instance, it was suggested that CSE international graduate assistants comment on their undergraduate students' incorrect answers by saying *this is a good try*. CSE international graduate assistants were also advised to encourage students to take another try by initiating a new turn in instruction by saying *any other thoughts* (classroom observation fieldnotes, August 8 and 9, 2017).

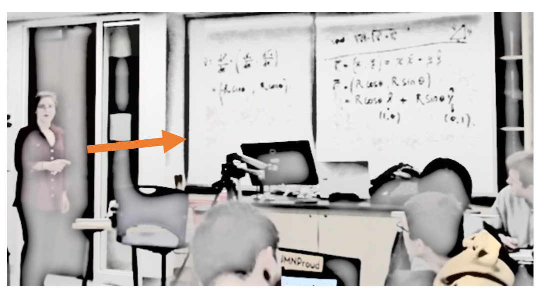
In the present dissertation study, once the focal physics international graduate assistant participants became more familiar with such institutionalized instructional responsibilities and expectations, they developed and rationalized (van Leeuwen, 2007) their own preferred instructional styles based on their physics expertise and mathematics agency (competence). These styles differed from what they were taught in the CSE Practicum program. Thus, all of the focal physics international graduate assistant participants took a more straightfoward approach to student incorrect answers in their instructional activities. Their primary concern was that students should know clearly what had led to a mistake in their physics and mathematics reasonings. Based on a number of informal conversations with my focal physics international graduate assistant participants, learning from mistakes can be critical for students so that they are able to apply physics knowledge to hypothesize and theorize explanations, design scientific experiments, analyze experimental data, and rationalize and explain physical phenomena with mathematics. Physicists should not be afraid of making mistakes in data analysis because mistakes create socialization spaces for physicists to re-conceptualize, re-examine, and overcome challenges. Excerpt 5 presents an example of this kind of straightforward feedback, in a lesson where Gina teaches the class how rotational quantities (e.g., the angle of rotation θ, angular velocity ω, and angular acceleration α) are related to one another in rotational kinematics. Gina teaches the class how to solve position vector questions with the rotational kinematic equations. She engages her students in this problem solving activity by asking them how the term $\frac{dr_x}{dt}$ located in the equation $\vec{v} = \frac{dr_x}{dt} + \frac{dr_y}{dt}$ can be replaced by the derivatives of $sine$ and $cosine$ (lines 4 and 5). When none of her students successfully answer the question, Gina then directly tells the class that the answer is wrong (line 24).

Excerpt 5: It's wrong

[Classroom discourse transcript: Gina, November 14, 2017]

1	Gina	This only holds in Cartesian direction
2		When you compose [these in Cartesian axes
3		*[points to $Rcos\theta\hat{x}$, and then $Rsin\theta\hat{y}$*
4		So, what is [this
5		*[points to $\frac{dr_x}{dt}$ in the equation $\vec{v} = \frac{dr_x}{dt} + \frac{dr_y}{dt}$*
6	Tom	[It can be the $Rsine$
7	Gina	*[draws a bracket and put an equal marker*
8		*writes symbol R*
9		[$Rsine$ of theta
10		*[adds θ*
11	Tom	Negative sign
12	Gina	[Negative
13		*[put a negative marker – before $Rsin\theta$*
14		What else
15	Tom	And then *R*
16	Gina	*adds a comma*
17	Tom	↓Yeah
18		And then [$Rcosine$ of theta
19	Gina	*[writes $Rcos\theta$, and then draws another bracket*
20	→	Do you all agree?
21	Ss	((*some students nod their heads*))
22	Gina →	Do you ↑all agree?
23	Ss	((*some students nod their heads again*))
24	Gina →	[It's <u>wrong</u> *[points to the whiteboard with her right index finger, while her students stopped nodding their heads*

Figure 49



25	→	What's wrong=
26	Vic	=I think, we need /`dʌblju/?
27	Tom	↓Yeah, like-
28	Vic	*R* /`dʌblju/
29	Gina	The /`dʌblju/
30		What is the /`dʌblju/
31		Yes?
32	Nick	(inaudible) the chain [rule

33 Gina [↓Yes
34 The chain rule
35 ↓Yes
36 Something that-
37 [This thing depends on time
38 [*draws an upward arrow over* $-Rsin\theta$*, and writes* $\theta(t)$

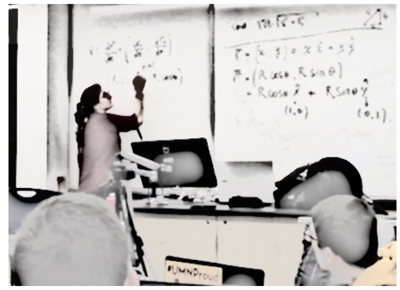


Figure 50

39 So, when you take the derivative, you chain- do the chain rule
40 So, [next to this, [derivative of theta, with respect to time
41 [*faces the equation* $(-Rsin\theta, Rcos\theta)$
42 [*next to* $-Rsin\theta$*, writes* $\frac{d\theta}{dt}$
43 [Derivative of theta, with respect to time
44 [*next to* $Rcos\theta$*, writes* $\frac{d\theta}{dt}$

In Excerpt 5, in lines 1-19, one student, Tom, works with Gina to complete the mathematical procedure on how the derivatives of $sine$ and $cosine$ replace the term $\frac{dr_x}{dt}$ in the equation $\vec{v} = \frac{dr_x}{dt} + \frac{dr_y}{dt}$ (lines 6-9). The mathematical expression on the whiteboard, $-Rsin\theta$ and $Rcos\theta$, visually shows to the class how the term $\frac{dr_x}{dt}$ located in the equation $\vec{v} = \frac{dr_x}{dt} + \frac{dr_y}{dt}$ is replaced with the derivatives of $sine$ and $cosine$ on the x-axis in a negative direction and on the y-axis in a positive direction.

After Gina and Tom complete the mathematical procedure together while Gina records Tom's responses on the whiteboard, in line 20, Gina asks the class if they all agree with the resulting mathematical expression $\vec{v} = sin\theta$ and $cos\theta$ she has written on the board. In line 21, some of her students nod their heads to show their agreement. In line 22, Gina asks again *Do you all agree* with a raised pitch on the word *all*. Her students nod their heads again as a response. In the subsequent turn (line 24), Gina then tells the class that this new mathematical expression is in fact incorrect; she says *it's wrong* with a stress on the word *wrong*. Simultaneously, she uses her right index finger to direct her students' attention to the new mathematical expression written on the whiteboard (see Figure 49).

Even though she has told her students bluntly that they have made an error, the problem-solving activity continues. With no observable pause in interaction, in line 25, Gina initiates a new turn by asking *what's wrong* to re-engage her students to work with her to examine where the problem is in the mathematical process. Immediately, with no pause, in line 26, another student, Vic, takes up the turn by saying *we need* /*`dʌblju*/ with a rising intonation at the end of the phrase. In line 27, his peer, Tom, supports his response with a discourse marker *yeah*. Vic self-repairs his earlier response by giving another response *R*/*`dʌblju*/ (line 28). Vic's self-repair can imply that he may know his first attempt is inaccurate (Schegloff, 2000). Unfortunately, Vic fails to repair his earlier turn because Gina asks how /*`dʌblju*/ is related to the mathematical expression in the subsequent turn (line 30).

Based on his reading of Gina's response to Vic, in line 32, Nick gives another try by saying *the chain rule*, answering Gina's question. Gina overlaps with Nick with the discourse marker *yes* (line 33). This overlapping, or more specifically, 'recognitional terminal overlapping' (Jefferson, 1983), signals an agreement achieved between the information recipient (Gina) and the information giver (Tom). Gina then takes back the conversational floor and explains what and how the chain rule is applied in rotational kinematic equations (line 34-44). Gina concludes the problem-solving activity by verbally explaining that time matters in the physics concept of rotational kinematics and by visualizing how the correct physical quantities replace the terms $\frac{dr_x}{dt}$ and $\frac{dr_y}{dt}$ in the equation with respect to time (see Figure 50).

The data in Excerpt 5 shown that in this case, Gina does not follow the advice on error correction given by the CSE Practicum program faculty. She corrects her students' wrong answers in a straightforward manner presumably in order to help her students see clearly their mistake in physics and mathematics reasoning. Gina does not let them dwell on their mistake; however, she re-engages her students in the problem-solving activity by initiating a new turn in instruction to continue the socialization process of making her students competent members of the physics community. This continuing socialization space reveals Gina's stronger expectations and views of effective physics instruction is. For Gina, it is much more important for her students to be able to identify what and where their errors are and how to overcome them, than to spend her instructional time devising what appropriate speech acts she sounds friendly.

In addition to rejecting in their classroom practices a recommended institutionalized structure of classroom interactional patterns (e.g., initiate a question-response to students in giving feedback), the focal physics international graduate assistant participants also challenged a disciplinary ideology involving the discourse genres of physics knowledge construction that is mediated through the integration of disciplinary spatial repertoires and mathematical symbolic systems. Unfortunately, even in a research field where the center of the focus is to study 'natural' phenomena using a scientific approach, white supremacy exists as a political ideology that perpetuates and maintains social-political-historical-institutional domination by whites over communities of color. For a great number of international graduate assistants who study in a white-dominated U.S. higher education institution, their research expertise is often ignored and unfairly judged as *incompetent* due to their language learner background. This linguistic discrimination experience is illustrated in Excerpt 6, in which Ian teaches his undergraduate physics students the fundamental components of writing a data analysis paper in physics discipline. In such a paper, undergraduate physics students are required to apply their physics and relevant mathematic knowledge in data analysis. This is part of the socialization process of becoming legitimate members of the physics community by showing they can use their physics knowledge logically to theorize and analyze the data collected from scientific experiments. Ian encourages his students to exercise their agency to define their own academic voices while sharing with his students a story about prior linguistic discrimination he experienced with a more experienced graduate assistant within the same department (lines 17-21).

Excerpt 6: And I’m like (0.2) >fuck you<

[Classroom discourse transcript: Ian, October 18, 2017]

1	Ian	In the Lab manual, there is good example and bad example
2		And the procedures written in paragraph is a good example
3		And written in a step-by-step is a bad example
4		Which I <↓disagree>
5		(0.2) Eh-
6		Because I think that the written in the order of-
7		Step-by-step order with (.) labels, with numbers is a better way to read a report
8		Although it’s not a good way to write a scientific writing
9		Because nowadays we don’t do this one, two, three labels in the published papers
10		However, this is not a published paper
11		And <also>

12			When you do eh-
13			When you give an official presentation, you use a PowerPoint
14			You still label things
15			And you do label clearly
16		→	So, I think this is still a good way to ↑write
17			And I discussed with (.) our >like< head TA
18			TA of the classes
19			And he said that-
20			Well, >that's<
21		→	[That's <how> English writes, so you don't know that
22			[*looks at the students*
23		→	[And I'm like (0.2) >fuck you<
24			[*looks at the surface of the podium*
25			[↓So
26	Ss		[☺☺
27	Ian	→	You write what you want, and I will read it

In Excerpt 6, at the beginning of his instruction (lines 1 and 2), Ian tells the class that the Lab manual includes a list of good and bad examples of Lab report as provided by the department of physics. Among those examples and writing requirements, Ian disagrees when the Lab manual simplifies that labeling the experimental procedures is a bad practice (lines 3 and 4). After a short pause, in line 7, Ian explains to the class his view that structuring a lab report with numbers can be more accessible to readers (e.g., course instructors) and a lab report is not a published paper (line 10). In addition, organizing an academic presentation PowerPoint with numbers can be more accessible to audience (lines 12-16). However, structuring a lab report with numbers is not following the academic writing genres for publication in physics disciplines (lines 8 and 9). Ian then tells the class that he shared his view about structuring a lab report with numbers with a departmental head teaching assistant (lines 17-18). Regrettably, as a more experienced course instructor, this male head teaching assistant was unable to give any disciplinary constructive advice but delivered a power-based piece of linguistic discrimination. This male head teaching assistant not only linguistically discriminated against Ian by saying *That's how English writes* with a stress on the word *English* and further saying *you don't know that* with a stress on the word *you* (line 21). This male head teaching assistant may position Ian as a 'linguistic *Other*' whose first language is not English and as a 'cultural *Other*' who has relatively less experience as a graduate instructor in a white-dominated and English-dominated institution. Here, *Others* are those who are marginalized by dominant power structures or do not fall into the categories of dominant cultures (García-Sánchez, 2013; McLaren, 1995). International graduate assistants are *Others* marginalized and excluded by dominant Whiteness language and culture ideologies as *problems* rather than *resources* with rich scientific knowledge, competence, and experience that can contribute meaningfully to science education in higher education contexts.

How did Ian reflect on this experience? In line 22, Ian says *And I'm like (0.2) >fuck you<* with a quicker speech on the last two words. The 0.2 second micro-pause in the phrase is interactionally salient in such conversation. This pausing behavior or hesitation within the turn construction unit might hedge or lessen the impact of a phrase due to the politeness constraints between interlocutors. Ian may know that profanity is socioculturally (and academically) inappropriate because he looks at the surface of the podium rather than his students when uttering those swear words. As a multilingual international graduate instructor and a student of the minoritized community, I understand how complicated and confused Ian might feel about different kinds of discrimination. Pausing behavior or hesitation allows a space in interaction in which a speaker can produce further talk in a context where an earlier talk can be reworked

(Wong, 2004). In the subsequent turn (line 25), Ian utters the discourse marker *so* beginning with a lower pitch, while his students laugh in line 26 as a response to his reflection shared in the prior turn (line 23). The discourse marker *so* resumes the socialization trajectory (Bolden, 2006)— that is, the interaction that socializes students into the academic cultures of scientific written discourse practices. This discourse marker *so* also launches new course of action— that is, in line 27, Ian's sentence *you write what you want, and I will read it* functions to close this socialization activity.

In Excerpt 6, Ian's experience sharing through his mini-narrative reflects how international graduate assistants' disciplinary competence and expertise can be underestimated by individuals who assert dominant Whiteness through a colonized lens of 'native-speakerism' (Holliday, 2006). The swear words uttered in line 22 not only reflects Ian's emotional response to the kind of linguistic discrimination he faces, but also exhibits Ian's enactment of disciplinary agency to resist covert and overt forms of privilege that normalize and reproduce systematic inequality and inferiority. In addition, the curse words in line 22, together with the closure sentence in line 27, create a multidiscursive and multivoiced space (Busch, 2014) in which undergraduate physics students as less experienced members can socialize themsleves to develop dialogues within their areas of study and to cultivate their own academic vocie representing their physics identity.

5.3 Discussion— Heteroglossic practices of physics socialization activities

5.3.1 Competing discourses of expertise between international graduate assistants and students or between students

Chapter 6 demonstrates that the competing discourses of disciplinary expertise within the physics discipline constitute an ongoing project. First, it is precisely the heteroglossic nature of physics socialization activities that enables an array of 'expertise' to rise to the surface. Second, in this study, the heteroglossic practices of physics discourses, combined with the international graduate assistants' awareness of student mathematics anxiety, ensured that there were 'release valves' for students in the form of 'carnival play' (Bakhtin, 1981), which helped mitigate tension and mathematics anxiety. In addition, the undergraduate students' pragmatic expertise facilitated their peers' participation in physics socialization activities when the international graduate assistants' communication of their disciplinary expertise momentarily faltered.

Ochs and her fellow colleagues (1994, 1996) suggest that, within the physics discipline, the construction of disciplinary expertise is mediated through the integration of the discursive features of physics discourses, including academic registers, mathematical symbolic systems, and communicative multimodalities. The present chapter highlights that, critical to competent participation in physics, classroom socialization requires physicists to draw on those discursive elements to contextualize their prior physics reasoning and future applications to present discussions about a physics event. Different from some social science disciplines (e.g., language education), meaning making in science communication and interactions is not always indexed through linguistic repertoires but through the incorporation of communicative multimodalities and mathematical symbolic systems. For instance, visual displays of a physics event being discussed are commonly applied by physicists to visualize abstract scientific realities. The intertextual reading of visual representations facilitates physics inquiry and enables translation of mental images into physics discourse practices (Kosslyn, Ganis, & Thompson, 2001; Uttal & O'Doherty, 2008). More importantly, the visual displays also function as a dialogic link connecting relevant heteroglossic practices of physics discourses (i.e. linguistic repertories and mathematical symbolic systems) for disciplinary expertise construction among physicists.

Competent participation in language-mediated socialization activities often involves full or nearly full command of discourse knowledge specific to a discipline. However, the present study argues that within the physics discipline, the socialization can occur even when undergraduate physics students (as less experienced members) lack full command of the disciplinary competence required for physics problem-solving activities. This may be due to the heteroglossic nature of physics discourse practices in that shared knowledge can be established through the confluence of language, multimodalities, and mathematics symbolism and images. The heteroglossic practices of physics discourses create a multivoicedness space for less experienced physicists to engage in either instructor-led or peer-oriented socialization activities, rather than being excluded from learning opportunities. Yet, in certain socialization activities where the non-physics-discipline registers cannot be comprehended, such as when international graduate assistants are unaware of the implicit pragmatic meanings signaled in interaction, imperfect socialization (He, 2016) may occur in which peer socialization spaces are created to potentially decentralize the international graduate assistants' disciplinary expertise and membership as course instructors and experienced physicists.

Language socialization into an academic discourse community involves hierarchical tension between more and less experienced members (Duff, 2010, 2012).

The present study notes that, within the physics discipline, the multiplicity of student disciplinary expertise and voices is reflected in the heteroglossic practices of competing discourses among undergraduate students. The findings in this article demonstrate that the multiple (and sometimes competing) voices exist in the heteroglossic interaction of a physics activity, and that some voices emerge as dominant in one moment while others emerge as dominant in others. For instance, when the focal physics international graduate assistants pause to rephrase an abstract physics concept (e.g., forces and their directions), their undergraduate students may choose to exercise their agency (Ahearn, 2001; Sayre & Irving, 2015) and take over the conversational floor to create a peer language socialization space within the international graduate assistants' instructional contexts. Further, during these peer socialization activities, more experienced undergraduate students may exercise their disciplinary discursive repertoires to compete against each other for superior expertise. This competition for expertise among undergraduates may temporarily decenter the international graduate assistants' positions as course instructors. However, in the present study, the focal physics international graduate assistant participant (Kelly) did not retreat from these peer socialization activities. She participated in the student-directed discourse by taking on the role of mediator or facilitator, giving a confirmation marker *yes* when she recognized the key words from the students' utterances that matched her physics knowledge. These competing discourses of expertise among undergraduate students are part of the negotiation processes of contextualizing the heteroglossic feature of physics communication.

Members of this physics classroom community deploy their linguistic and multimodal repertoires and mathematics knowledge in interaction as means of navigating and structuring role-relationships. The preset study illustrates that the increased competing interactions among undergraduate physics students can function as humorous carnival play within the broader classroom problem-solving activities, which helps alleviate peer mathematic anxiety, provides support, and liberates the institutionalized ideology about what a competent and proficient physicist is.

5.3.2. Competing discourses of expertise between international graduate assistants and institutionalized practices

In the CSE Practicum program, CSE international graduate assistants were socialized into the institutionalized classroom communicative practices and cultural expectations related to STEM instruction in U.S. higher education. During the international graduate assistant-led instructional activities where undergraduate physics students were unable to successfully answer instructor questions, the international graduate assistants were advised to correct student responses in a positive manner (e.g., smile) to help mediate student mathematics anxiety and to encourage students for one more try. However, the focal physics international graduate assistant participants exercised their agency (disciplinary competence and mathematics agency) to problematize those recommended classroom practices. They rationalized (van Leeuwen, 2007) their own preferred instructional styles, based on their rich experiences in physics discipline. Such kind of instructional practices taught in the CSE Practicum program might not meet the core values of physics/science disciplines— that is, based on what I learned from my focal physics international graduate assistant participants, learning from mistake can be essential to becoming a competent member of the physics discourse community. Physicists should not be afraid of making mistake because learning from mistake could create socialization opportunities to re-conceptualize, re-examine, and overcome challenges.

Within the physics discipline where members study the ‘natural’ phenomena with a scientific approach, white supremacy still colonize, perpetuates, and maintains its social-political-historical-institutional domination over the communities of color. The present chapter asserts that an analysis of the heteroglossic nature of physics discourse practices gives insight into the dynamic multiplicity of physics instructional interactions led by international graduate assistants. The insight can problematize current discussions that devalue international graduate assistants as *problems* rather than *resources* with rich scientific competence and experience that can contribute meaningfully to the STEM education in higher education.

Chapter 6 Conclusion

In Chapter 6, I will recapitulate findings and discussions from Chapters 4 and 5, concerning the chronotopic nature of physics discourse practices and instructional interactions that link prior logical reasoning and future applications to present discussions about a physics event; and the competing discourses of expertise through heteroglossia practices between undergraduate students and between physics international graduate assistants and institutionalized ideological forms of knowledge construction. Following this, I consider implications of this research for linguistic anthropology scholarship concerning language socialization as well as for research methods for the study of socialization activities involving disciplinary spatial repertoires and mathematical symbolic systems.

6.1 Physicists as light-beam riders: Chronotopes of physics socialization activities

Chapter 4 examined the chronotopic nature of physics discourse practices and socialization activities between bi/multilingual physics international graduate assistants and their undergraduate students. I applied Bakhtin's (1981) construct of chronotope to explore how meanings are constructed through chronotopic (re)contextualization of physicists' prior physics reasoning and future applications in present discussions about a physics event. Chronotopes of physics discourse practices require physicists' interpretive journey through the integration of disciplinary spatial repertoires and mathematical symbolic systems.

Bakhtin's (1981) chronotope emphasizes the spatiotemporal link mediated through the indexicality of semiotic signs available for realization and instruction. Within the physics discipline, the construct of chronotope highlights the sequential and simultaneous contributions to meaning making that are mediated through disciplinary spatial repertories and mathematical symbolic systems audible and visible to participants. The chronotopic link, through the linguistic, multimodal, and mathematical features of physics discourse practices, creates a dialogic space in which multilingual practices of knowledge construction can be achieved through multimodal resources of spatial repertoires. When physics reasoning cannot be completed through sequential, multilingual practices of the instruction, simultaneous use of embodied communicative multimodalities (e.g., gesture movements) or visual representations serve as a spatiotemporal link connecting translingual practices to physics reasoning. This simultaneous chronotopic activity that links translingual nature of spatial repertoires to physics reasoning "accommodates the fact that selective words from different languages would find coherence for situated activities in combination with other nonverbal resources" (Canagarajah, 2018, p. 275). Simultaneous chronotopic activity also maintains the sequential chronotope in instructional interactions to engage undergraduate students in joint meaning making activities (Goodwin, 2018).

An intertextual network of simultaneous and sequential chronotopes helps facilitate scientific inquiry, physics reasoning, and error analysis, enabling translation of scientific thoughts into discourse practices (Uttal & O'Doherty, 2008). Meaning construction in physics socialization activities is not always indexed through linguistic repertoires. The incorporation of physics notations, mathematics equations, and multimodal nature of spatial repertoires also plays crucial role in knowledge construction in physics disciplines. Often the visual representations were used by international graduate assistants and their undergraduate students as an interactional link between linguistic repertoires and mathematical knowledge. Multimodalities then became active resources for meaning making in physics socialization activity and were in constant dialogue with other resources of spatial repertoires (Canagarajah, 2017, 2018).

Within the physics discipline, the process of becoming a competent physicist entails understandings of how disciplinary spatial repertoires and mathematical symbolic systems are used to acquire and express disciplinary expertise. In Chapter 4, findings demonstrated that when undergraduate students (as less experienced physicists) lacked full command of the academic language to contribute to knowledge construction, the use of multimodal resources of spatial repertoires as epistemic support helped create a dialogic space to move the socialization activity forward. Experimental materials as epistemic resources in physics communication provided insight into how physics discourse practices were situated in the holistic contexts of everyday experience, and how academic language were not in isolation from materials resources in meaning making in physics socialization activities.

6.2 Competing discourses of expertise: Heteroglossia of physics socialization activities

Chapter 5 presented data on the challenges related to disciplinary discourse practices that bi/multilingual physics international graduate assistants and their undergraduate students encountered in socialization activities. It also addressed how international graduate assistants and their undergraduate physics students engaged with those challenges to facilitate the socialization processes within physics discipline. I applied Bakhtin's (1981) concept of heteroglossia to examine how disciplinary expertise was constructed through the confluence of disciplinary spatial repertoires and mathematical symbolic systems between international graduate assistants and their undergraduate physics students. The chapter also considered how increased competing interactions among undergraduate physics students in international graduate assistant-led learning contexts created spaces for peer language socialization. In addition, findings in Chapter 5 documented the way disciplinary ideology and agency in physics instructional interactions reflected a centripetal-centrifugal tension between the physics international graduate assistants and institutionalized ideological forms of knowledge construction.

The competing discourses of disciplinary expertise within the physics discipline presented an ongoing project. First, the competing discourses of expertise reflected the heteroglossic nature of physics socialization activities which enabled a number of legitimate ways of demonstrating expertise. Second, the heteroglossic practices of physics discourses, combined with the international graduate assistants' awareness of student mathematics anxiety, ensured that there were 'release valves' for undergraduates in the form of carnival play (Bakhtin, 1981). Carnival play between undergraduates helped mitigate student mathematics anxiety. Finally, the undergraduates' pragmatic expertise facilitated their peer socialization activities when their international graduate assistants' communication of disciplinary expertise momentarily faltered.

Competent participation in language socialization activities often requires full or nearly full command of discourse knowledge specific to a discipline. However, Chapter 5 contested that assumption within the physics discipline, in that socialization could occur even when undergraduate physics students (as less experienced members) lacked full command of the disciplinary competence required for physics problem-solving activities. The heteroglossic practices of physics discourse practices created a multivoicedness space for undergraduates (as less experienced physicists) to engage in either instructor-led or peer-oriented socialization activities, instead of being excluded from learning opportunities. Moreover, in some socialization activities where non-physics-discipline registers could not be understood, such as when physics international graduate assistants were unaware of the implicit pragmatic messages signaled in interaction, peer socialization spaces were created to potentially decentralize the international graduate assistants' expertise and membership as course instructors.

The competition for expertise among undergraduates were shown to occasionally temporarily decenter the international graduate assistants' position as physics instructor. In the present study, in such cases the focal physics international graduate assistant participants did not retreat from their students' peer socialization activities. The international graduate assistants listened to their undergraduates' conversational exchanges and participated in the student-directed discourse by taking on the role of facilitator, using the confirmation marker *yes* when she recognized and affirmed the key words in the students' utterances that matched their physics knowledge.

6.3 Spatial repertoire-informed chronotopic turn in scientific socialization activity

I now turn to address implications that the present dissertation study has to linguistic anthropologic research of socialization activities that involve disciplinary spatial repertoires and mathematical symbolic systems.

The present dissertation contributes to the field of linguistic anthropology by applying Bakhtin's (1981) dialogism of chronotope and heteroglossia and spatial repertoires (Canagarajah, 2017, 2018) to explore the dialogic nature of physics discourse practices and instructional interactions by bilingual professionals in physics. The analysis and findings in Chapters 4 and 5 have demonstrated how meanings are constructed *in situ* within science disciplines through chronotopic (re)contextualization of disciplinary spatial repertoires and mathematical symbolic systems, and how discipline-specific discourse practices shape the socialization activities between bi/multilingual international graduate assistants and their undergraduate physics students. Central in the discussions is the sequential and spatial nature of repertoires that serve as collective assemblages through which both international graduate assistants and their undergraduate physics students establish physics knowledge in a chronotopic manner.

The physics discourse and instructional practices that are mediated through the integration of disciplinary spatial repertoires and mathematical symbolic system reflect not only the synchronic juxtaposition of discursive practices related to multiple physical spaces, but also the diachronic dimension in which present actions link back to prior logical reasoning and forward to future applications. The simultaneous and sequential engagement in physics instructional activities facilitate and is shaped by the weaving of intertextual network across the confluence of verbal descriptions, multimodalities, and mathematical symbolic systems. The present dissertation study suggests the usefulness of a spatial repertoire-informed chronotopic *turn* in analyzing sciences discursive and instructional activities across time and space. Thus, it enables us to more thoroughly understand the chronotopes of scientific communication in which scientists participate in collaborative interpretative activities, journey through their disciplinary spatial repertoires, and transport themselves into the constructed visuospatial representations and physics/mathematical reasoning of scientific phenomena.

The spatial repertoire-informed chronotopic perspective provides a robust framework to theorize and analyze the diversity, complexity, and dynamism of instructional communication by bi/multilingual professionals. These practices highlight the inseparability of time and space in meaning making process— that is, the spatiotemporal link across the confluence of academic language in physics, repertoires embedded in the material environment, and mathematical symbolic systems. A consideration of such a spatial repertoire-informed chronotopic turn is essential to understanding the dynamic multiplicity of scientific communication by bi/multilingual populations in academic contexts.

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Appendix: Transcription Conventions

The convention system used to transcribe the data includes the following codes that form part of the transcription system in Conversation Analysis. The system was developed by Gail Jefferson in the 1970's and has been adopted and expanded since that time (Schegloff, 2007).

-	(hyphen) abrupt cut-off
::	(colon(s)) prolonging of sound
?	(question mark) rising intonation
=	(equal sign) latch or continuing speech with no break in between
word	(underlining) stress
°word°	(degree symbols) quiet speech
↑word	(upward arrow) raised pitch
↓word	(downward arrow) lowered pitch
>word<	(more than and less than) quicker speech
<word>	(less than and more than) slower speech
(.)	(period in parentheses) micro-pause: less than 0.2 second
(0.4)	(number in parentheses) length of a silence in tenths of a second
[	overlapping verbal talk or nonverbal communication; point of overlap onset
]	simultaneous verbal talk or nonverbal communication: point at which utterance terminates
word	*word* in italic font is used for nonverbal communication overlapping with verbal talk or when there is no verbal talk between interlocutors
.hh	(h's preceded by dot) aspiration or inhalation
☺	(smiling face) laughter in conversation