Facilitating Student Engagement in Undergraduate Mathematics Lectures:

A Multimodal Investigation

By

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Abstract

University students' success in core mathematics courses has been linked to their overall academic achievement in many undergraduate programs. This finding has prompted an ongoing inquiry into the way mathematics is taught, focusing, specifically, on the university mathematics lecture--the most common instructional activity--and on the extent to which it is conducive to student engagement, regarded as key to successful learning. This dissertation reports on a multimodal study of student engagement in undergraduate mathematics lectures with the purpose to develop a context-specific understanding of student engagement, and identify and describe aspects of university mathematics teaching that impact student engagement. A theoretical and analytical framework combining concepts from discourse studies, Vygotskian sociocultural theory, situated learning, multimodality, speech theory, and gesture studies is used to investigate university mathematics teaching as a complex discursive practice. The study responds to the following research questions: 1) What constitutes student engagement in the university mathematics teaching context? How can it be defined? 2) What aspects of the classroom context affect student engagement? and 3) What strategies do university mathematics instructors use to help realize student engagement in lectures? A mixed methods study with an explanatory sequential design was conducted wherein the results of the first phase of data collection and analysis, involving student surveys and interviews with university mathematics instructor participants, informed the second phase involving the collection and analysis of video-recorded lectures, observational field notes, and follow-up interviews with instructors. Based on the study findings, a context-specific definition of student engagement in mathematics lectures is developed, and the aspects of the learning environment and classroom climate impacting student engagement are identified and discussed. The study indicates that by using embodied multimodal patterned strategies, university mathematics instructors facilitate student engagement by establishing and maintaining a continuous focused interaction with the students and by involving students in the collaborative process of doing mathematics in real-time. The study outcomes have implications for future research into university lecturing in face-to-face and online teaching contexts, and the development of programs and materials for university teaching and training new faculty.

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Abbreviations

DCP – Document Camera Projector

ESP – English for Specific Purposes

ICAP – Interactive, Constructive, Active, Passive

IP – Instructor Participant

K-12 – Kindergarten through Grade 12

L1 – First language

MIA – Multimodal (Inter)action Analysis

penTPC – Pen enabled Tablet PC

PPT – PowerPoint

QMTA – Qualitative Multimodal Thematic Analysis

RGS – Rhetorical Genre Studies

SR – Student Respondent

STEM – Science, Technology, Engineering, Mathematics

TA – Teaching Assistant

ZPD – Zone of Proximal Development

Transcription Notations

"Text"	– Text in quotation marks indicates direct speech
Text	– Italicized text within participant quotes indicates direct speech is emphasized with vocal stress
Text	– Bolded text within participant quotes indicates direct speech is emphasized with increased volume
…	– Ellipsis indicates omitted material
Text	– Text enclosed in asterisks indicates a nonverbal action
Text	– Sloping text is used to convey intonation when relevant (e.g., text sloping upward represents rising intonation, whereas text sloping downwards represents falling intonation)
[Text]	– Text enclosed in square brackets within direct quotations indicates material added to the quotation. Text enclosed in square brackets but not within direct quotations (occurs in Chapter 9, Section 9.2.2, Figures 25 and 26 only) identifies speech acts or silences
-Text-	– Text enclosed in short dashes following square brackets identifies speech-act silences (occurs in Chapter 9, Section 9.2.2, Figures 25 and 26 only)
(*text*)	– Italicized text enclosed in round brackets indicates that the speaker is gesturing during the articulation (occurs in Chapter 9, Section 9.2.2, Figures 25 and 26 only)

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Glossary

Action: Human activity as participation in society; people "doing things" (Austin, 1975; Scollon, 1998, p. 8).

Chalk talk: The main "*way*" (Artemeva & Fox, 2011, p. 22) mathematics instructors around the globe teach undergraduate mathematics in university (Artemeva & Fox, 2011). Chalk talk has been described as consisting of instructors writing on the chalkboard while providing a running commentary on what is being written, turning to the students and talking about what has been written, moving from one part of the board to another, pointing at different parts of the board during explanations, and so on (Artemeva & Fox, 2011).

Checking: The instructional practice of gauging students' comprehension or understanding of the material while teaching. Checking is usually executed by the instructor explicitly asking if students in the classroom understand and/or are following while looking at students (either looking at individual students or looking across the audience of students by gazing from one side of the classroom to the other using a pan-gaze).

Coding: Categorizing segments of data under a short name that simultaneously summarizes and accounts for each piece of data (Charmaz, 2006, p. 43).

Combined theoretical and analytical framework: A combined framework provides the structure to define the theoretical, methodological, and analytical approach of the research study (Grant & Osanloo, 2014, p. 13), connects the researcher to existing knowledge (Laberee, 2019, para. 2), and presents a lens through which the entire study may be viewed (Creswell & Plano Clark, 2011, p. 10). It includes concepts, existing theories, and analytic models that are relevant to the dissertation inquiry.

Deictic gesture: A pointing gesture (commonly produced by extending the index finger or open hand).

Discourse communities: Swales defines discourse communities as "sociorhetorical networks that form in order to work towards sets of common goals" (p. 9), and provides a list of six criteria that define groups of individuals as discourse communities (see Chapter 2, Section 2.2 of this dissertation).

Document camera projector (DCP): A projector mounted on a desk or over a writing surface that projects the surface below it onto a large screen(s). In the context of the present study the DCP project the instructors' writing of mathematical notation using a pen on paper.

Student engagement: No unified definition of student engagement exists within current research literature. There is some consensus that student engagement can be defined as "the direct, measurable involvement or participation in learning activities" (Gettinger & Walter, 2012, p. 653), generally associated with students' overall academic achievement, motivation, and success.

Engagement construct: An aspect that contributes to the overarching-construct of engagement.

Engagement device: A rhetorical strategy used by a speaker (or writer) to engage with their audience (see Hyland, 2001, 2005).

Frozen action: A mediated action embedded in an object or disembodied mode (Norris, 2004, 2011, 2014; Norris & Makboon, 2015). For example, an article of clothing, a painting, a piece of furniture etc..

Gatekeepers: In this dissertation, gatekeepers refer to introductory core (required) science, technology, engineering, and mathematics (STEM) courses which either implicitly or explicitly function to eliminate all but top tier students from enrollment (Gasiewski et al., 2012, pp. 229-230).

Genre: Traditional approaches to genre view genre as stable *text types* characterized by their textual regularities, that is, as classifications of written texts categorized according to static surface-level forms and features. Genre (as used here) refers to *non-literary* genres, that is, ways of *doing things* in the social world that, over time, have become typical or recognizable (for a detailed history of traditional approaches to genre and the evolution of genre studies see Bawarshi & Reiff, 2010). Non-literary genres have been described as "relatively stable types" of utterances (Bakhtin, 1986, p. 60) used to participate in social situations. Examples of non-literary genres include resumes, tax forms, recipes, newspaper articles, and more recently, personal blogs, or tweets. These ways of communicating have been developed to address the needs of certain social situations and, as they are adopted and used, become easily recognizable to the people who use them.

Gesture: An action produced with the body or part of the body (e.g., one hand or both hands) with "the features of manifest deliberate expressiveness" (Kendon, 2004, p.15).

Gesture phase: Individual units of gestural movement (see Bressem & Ladewig, 2011; Ladewig & Bressem, 2013) that, when performed in succession, form a gesture (see also *gesture unit*).

Gestural silence: Gestural stillness (i.e., stillness of the hands) used to create specific communicative meanings when read in context (Fogarty-Bourget, 2016; Fogarty-Bourget, Artemeva, & Fox, 2019).

Gesture unit (or movement excursion): A series of gesture phases (Kendon, 2004) that, when performed in succession, form a gesture unit. The gesture unit begins when the hand departs from the *rest position,* also referred to as the "home position" (Sacks & Schegloff, 2002, p. 137), into a *stroke* (i.e., the movement of the gesture that "peak[s]" [McNeill, 1992, p. 83] or is "accented" [Kendon, 1975, p. 357]), where it is sometimes held for a moment (a post-stroke *hold)*, before returning to the rest position (*recovery/retraction*).

Grounded theory: A systematic, inductive, and comparative research method used for constructing theory from data (Charmaz, 2006). Grounded theory was originally developed by Glaser and Strauss (1967) as an approach to qualitative inquiry. While *traditional* grounded theory is still widely used, variations of the approach including *evolved* (e.g., Strauss & Corbin, 1994) and *constructivist* grounded theory (Charmaz, 2006, 2012) have been developed and popularized for use in both qualitative and quantitative research.

Higher-level action: The lower-level- mediated action is "the smallest interactional meaning unit" (Norris, 2004, p. 11) used in interaction. This means that it is the smallest complete action that carries meaning, for example a single hand or eye movement. A higher-level action is a mediated action "made up of a multitude of chains of lower-level actions" (Norris & Makboon, 2015, p. 44). For example, a greeting, or a mathematics lecture.

(Inter)action: An action performed by an individual. Norris (2004, 2011) uses parentheses around INTER in order to emphasize the idea that all actions are interactions. She states that "even when one social actor acts alone, the social actor acts with or through (always multiple and multimodal) physical and cognitive/psychological/embodied/socio-cultural mediational means as they interact with objects and the environment" (2014, p. 184).

Interaction (unfocused and focused): Goffman (1967) describes face-to-face interaction as "the class of events" (i.e., of human activity) "which occurs during co-presence and by virtue of co-presence" (p. 1). Unfocused interactions occur when individuals are co-present but not involved in a cooperative communicative exchange. Focused interactions occur when individuals are co-present *and* cooperating in a shared communicative exchange (Goffman, 1963, 1967). Focused interactions can be initiated through touch, talk, bodily orientation, "or by briefly establishing mutual gaze" (Andrén, 2014, p.160) and are maintained via sustained mutual communicative activity.

Involvement: In the context of this dissertation, involvement refers to students' cognitive implication in the material of the lecture realized through behaviours such as writing in their notebooks, "active listening", and displaying comprehension or "following along".

Illocutionary force: The *communicative* meaning of the utterance (i.e., the effect the utterance is intended to have on a listener) (Austin, 1975).

Locutionary force: The *literal* meaning of what is said (Austin, 1975).

Lower-level action: “the smallest interactional meaning unit” (Norris, 2004, p. 11) used in interaction. This means that it is the smallest complete action that carries meaning, for example a single hand or eye movement. See also *higher-level action*.

Mediated action: Individuals acting in society (i.e., participating in discourse) with and through cultural tools or mediational means (tools or objects used by social actors to participate in society, for example, language, symbols, gesture [Scollon, 1998; Wertsch, 1991].

Mediational means or cultural tools: Tools and objects used by social actors to act (do things) in society (Scollon, 1998; Wertsch, 1991). See also *mediated action*.

Mode: Most simply, a mode is described as any way (for example through speech, gesture, gaze, image, sound) of conveying meaning (see Kress & Van Leeuwen, 1996/2006). In multimodal mediated theory and multimodal (inter)action analysis (MIA), mode is defined as *systems* of mediated action recognizable by the rules and regularities attached to them (Norris, 2013, p. 278). The term multimodality has been used to recognize the ways that different meaning-making means (modes) intertwine and co-occur.

Modal complexity: Modal complexity refers to the intertwining of multiple modes in the production of an action (Norris, 2004, 2011).

Modal density: Modal density is a compound notion that involves both modal complexity and modal intensity (Norris, 2004, 2011). Within the multimodal (inter)action analysis (MIA), modal density is a conceptual tool for analysing the degree of attention and awareness of social actors in interaction. High modal density can be achieved through the use of high modal complexity, or high modal intensity, or both high complexity and intensity. The more complex or intense the modes of communication are (i.e., the higher the modal density), the more attention a social actor pays to the action(s) being produced (Norris, 2004). In other words, high modal density becomes a locus of attention in interaction. See also *modal complexity* and *modal intensity*.

Modal intensity: Modal intensity refers to the relative strength, weight, or importance of a particular mode (Norris, 2004a; Pirini, 2014), or more specifically, heightened pragmatic salience occurring as a result of an action being made prominent relative to surrounding or co-occurring actions (Fogarty-Bourget, 2018; Fogarty-Bourget, Pirini, & Artemeva, n.d.).

Multimodal (inter)action analysis (MIA): A methodological approach that enables the multimodal analysis of the "multiplicity of (inter)actions that social actors are simultaneously engaged in" in everyday situations (Norris, 2011, p. 2).

Multimodality: A term used to recognize the ways that different meaning-making means, commonly referred to as *modes* (for example, speech, gaze, movement, image, writing, etc.), intertwine and co-occur to construct communicative actions or multimodal wholes (also called gestalts).

Pan-gaze: In the context of this dissertation, a pan-gaze refers instructor behaviour of observing the students seated in the classroom by looking from one side of the classroom to the other (often using for *checking*).

Perlocutionary effect: The way an utterance is taken up by a recipient (Austin, 1975).

Qualitative Multimodal Thematic Analysis (QMTA): A method of coding developed for analysing rich, multimodal data including video and audio recordings paired with transcripts (Fogarty-Bourget, 2013).

Saturation (also called theoretical saturation): The point when fresh data no longer spark new theoretical insights nor reveal new properties of theoretical categories (Charmaz, 2006, p. 113; Glaser & Strauss, 1967).

Social actor: An individual acting in society.

Teacher persona: The "character" a teacher plays while teaching (Artemeva & Fox, 2010, p. 177). Instructors can construct a persona that is "welcoming" (using humour, being personable, supportive, and available to students) or "distancing" (conveying excessive formality, a general lack of warmth, and/or negativity towards students) (p. 177).

Text: In common parlance, the term *text* is used to refer to a piece of writing or written utterance. More recently, and across various areas of study, a text is understood as a unit of discourse. In this sense, a text can involve multiple meaning-making means and thus may be written, spoken, and/or enacted instantiations of communicative action.

Text types: Text types that are socially recognized are commonly referred to as genres. From the RGS perspective, Coe (2002) describes a genre as "the motivated, functional relationship between text type and rhetorical situation" (p. 197), that is, RGS scholars see genre as both "the situation and the textual instantiation of that situation" (Bawarshi, 2000, p. 357). From such a perspective, to identify a text type as a genre, it must have a clear and identifiable social purpose.

Theoretical framework: A theoretical framework consists of concepts and, together with their definitions and reference to relevant literature, existing theory that is used for studying a phenomenon of interest (Laberee, 2019).

Unit of analysis: The unit of analysis, as defined by Geisler (2004), is that which "identifies the level at which the phenomena of interest occurs" (p. 29); it the smallest indivisible unit which "retains all the basic properties of the whole and which cannot be further divided without losing them" (Vygotsky, 1962/2000, p. 4). As Matusov (2007) suggests, the unit of analysis must always be shaped by "the purpose of the researcher and the material of the study" (p. 308). Being that my phenomenon of interest is engagement in undergraduate chalk talk lectures, I take the *system of classroom practices of an undergraduate mathematics course* as my overarching unit of analysis.

Utterance: Bakhtin (1986) explains that social actors participate in social spheres through language in the form of spoken or written utterances. Bakhtin defines utterance as a "link" in the chain of communication (p. 91) where each utterance occurs *in response* to an earlier utterance and will itself evoke a response *infinitum*. In this dissertation I adopt Kendon's (2004) definition of utterance as "any unit of activity that is treated by those co-present as a communicative 'move', 'turn' or 'contribution'. … Such unit of activity may be constructed from speech or from visible bodily action or from combinations of these two modalities" (p. 7).

Zone of Proximal Development (ZPD): The discrepancy between a child's actual level of development (what the child can accomplish independently) and the level that can be reached with assistance from a more capable peer (Vygotsky, 1987).

Preface

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Contributions of Authors

Some of the publications that are partially reproduced in this dissertation are coauthored. Contributions of the authors are described as follows:

• (with A. Artemeva & J. Fox). Gestural silence: An engagement device in the multimodal genre of the chalk talk lecture. In C. Sancho Guinda (Ed.), *Engagement in professional genres: Disclosure and deference*. Amsterdam: John Benjamins.

Portions of the dissertation were based on 4 conference presentations:

The 7th Conference of the International Society for Gesture Studies, 2016 (my sole authorship); the 6th New Zealand Discourse Conference, 2017 (my sole authorship); the 2nd International Workshop of Discourse, Multimodality and Experimental Methods, 2018 (my sole authorship); the 2nd International Workshop of Discourse, Multimodality and Experimental Methods, 2018 (coauthored with my supervisor, Professor N. Artemeva).

Permission to reproduce has been provided by all co-authors.

Ethics Approval for Research Involving Human Participants

The study reported in this dissertation received research ethics board approval certificates from the universities involved. In order to protect the identities of the research participants, I do not append research clearance certificates that identify participating universities and countries.

Chapter 1: University Mathematics Lecturing, Gatekeeping, and Engagement

. . . the blackboard is as much a stage as a writing surface.

(MacKenzie & Barany, 2014, p. 12)

The way that mathematics is taught to undergraduate students has been the subject of much scrutiny because students' success in first-year mathematics courses has been inextricably linked to their overall academic achievement, and attainment of degrees in Science, Technology, Engineering, and Mathematics (STEM) disciplines. For instance, introductory undergraduate mathematics courses have been described as "*gatekeepers*" for those pursuing careers in STEM (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012, pp. 229-30; emphasis added), which means that these core courses function implicitly or explicitly to eliminate all but top tier students from enrollment.

Traditional undergraduate mathematics instruction includes lecture-style courses and, associated with them, problem solving and seminar sessions, or tutorials (e.g., Bergsten, 2012; Neumann, 2001; Speer, Smith, & Horvath, 2010; see also Speer, 2008 for a detailed description of problem-solving and/or discussion sessions that commonly accompany large-lecture style mathematics courses). Speer et al., (2010) identify the mathematics lecture as the most common instructional activity used at the post-secondary level, "where teachers present the content to be learned, orally and written on some display device (overhead projector, blackboard, or whiteboard), and students listen and take notes" (p. 101)[1]. This main "way" that instructors follow to teach undergraduate

[1] University mathematics teaching is discussed in-depth in Chapter 4 of this dissertation.

mathematics in university, dubbed "*chalk talk*", (Artemeva & Fox, 2011, p. 22), consists of instructors writing on the chalkboard[2] while providing a running commentary on what is being written, turning to the students and talking about what has been written, moving from one part of the board to another, pointing at different parts of the board during explanations, and so on. As has been observed in empirical studies of university mathematics lecturing, this method of teaching mathematics is "predominantly not talking 'about' mathematics, but actually 'doing' mathematics at the board" (Greiffenhagen, 2008, para. 35; see also Viirman, 2015). Chalk talk developed as a way of teaching university mathematics within the global community of mathematics professors as a situated disciplinary practice (Artemeva & Fox, 2011; Fox & Artemeva, 2012). Discourse of teaching mathematics combines writing, spoken language, and

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[2] University mathematics instructors also commonly use whiteboards in lieu of chalkboards, or more recently, devices which project the instructor's writing onto large screens. Regardless of the medium used to make the instructor's writing publicly visible to students in the classroom, the style of teaching involves the instructor's widely observable writing of text and mathematical notation while articulating what is being written, then shifting from the writing and providing commentary to talking *about* what was written and providing explanation. In this dissertation, I use the term chalk talk broadly to refer to this principal "way" of teaching university mathematics to undergraduate students, regardless of the medium used to teach the lectures (cf. Artemeva & Fox, 2010, 2011; see also Fox & Artemeva, 2012 who use the term chalk talk to refer to university mathematics teaching with either chalk and blackboards or markers and whiteboards).

mathematical symbolism (cf. O'Halloran, 2005), thus, as Sfard (2014) articulates, a study of university mathematics teaching is a study of written and spoken discourse, and, as such, chalk talk can be seen as a complex and embodied discursive pedagogical practice which blends multiple resources for meaning-making (Fogarty-Bourget, 2013; Fogarty-Bourget, Artemeva, & Fox, 2019; Fox & Artemeva, 2012; O'Halloran, 2005).

Certain scholars (e.g., Gasiewski et al., 2012; Gerofsky, 2010; Paoletti et al., 2018; Yusof & Tall, 1998) have voiced concern that the "gatekeeping" nature of undergraduate mathematics courses in STEM disciplines, and the chalk talk method of teaching itself, may encourage rote learning and be detrimental to *student engagement*. Student engagement has been regarded in the literature as key to successful learning and students' academic achievement from kindergarten through grade 12 (K-12) and post-secondary education (Chi et al., 2018; Finn & Zimmer, 2012; Fredricks, Blumenfeld, & Paris, 2004; Fredricks et al., 2016; Gasiewski et al., 2012; McMahon & Portelli, 2004). While no unified definition of student engagement exists within current research literature (see Dunne & Owen, 2018; Padgett et al., 2018), there is some consensus that student engagement can be defined as "the direct, measurable involvement or participation in learning activities" (Gettinger & Walter, 2012, p. 653), generally associated with students' overall academic achievement, motivation, and success. As mentioned, some research suggests that undergraduate mathematics lectures do not engage students and encourage passive, transmission-style learning (e.g., Yoon et al., 2011); however, there is an equally substantial body of literature which describes mathematics lecture learning contexts (discussed in-depth in Chapter 4 of this dissertation) as highly engaging and interactive sites of rich learning (e.g., Black, 2005;

Rodd, 2003; Speer, 2008). Other authors (e. g., Wood, Joyce, Petocz, & Rodd, 2007) note variance between individual lectures, where “good lectures can inspire and motivate learning, yet some lectures make students bored, confused, anxious, frustrated and even angry. And, in the middle lies the ordinary, day-to-day mathematics lecture that occurs in universities across the globe” (p. 907). Differences in instructors’ pedagogical and communicative strategies may be partially responsible for the contradicting views on chalk talk teaching as presented in the literature; for example, Gasiewski and co-authors (2012) have demonstrated that students’ perceptions of STEM lectures as engaging or unengaging are largely influenced by the teaching strategies that their course instructors employ.

The vast spectrum of chalk talk lectures’ characterization from dry, dull, and unengaging to them as sites “for awe and wonder” (Rodd, 2003, p. 15) may stem from a dearth of empirical research on the actual teaching practices, both verbal and nonverbal, used by instructors of undergraduate mathematics, which, according to Iannone and Miller (2019), remain largely under explored (see also Speer et al., 2010). While some attention has been paid to linguistic strategies used by mathematics instructors at different levels of teaching (e.g., Jamison, 2000; Schleppegrell, 2007), only a limited number of studies (e.g., Iannone & Miller, 2019) focused on the relevance of instructors’ use of nonverbal behaviours to student engagement, but even those studies, as Looney, Jia, and Kimura (2017) point out, “have lacked attention to gesture and the use of video data to support and present their analyses” (p. 47). Indeed, there has been little empirical insight into the subtle or nuanced strategies used by mathematics instructors to engage students and the impact that interactions with instructors might have on students’ engagement, particularly at the post-secondary level. Furthermore, despite much research on the phenomenon of student engagement (e.g., Dunne & Owen, 2013; Finn & Zimmer, 2012; Fredricks et al., 2004; Padgett et al., 2018), there appears to be a dearth of empirical evidence from a discourse studies perspective, including that which provides analyses of instructors' nonverbal teaching strategies.

This dissertation reports on a study that was prompted by the lack of such studies and by differing views of student engagement in chalk talk lecturing. Because chalk talk lecturing has been criticized by some for an inherent lack of student-instructor interaction (e.g., Croft & Ward, 2001; Gerofsky, 2010), and yet because previous research suggests that chalk talk is, in fact, a highly interactive form of instruction (e.g., Fogarty-Bourget, 2013; Fogarty-Bourget, Artemeva, & Fox, 2019; Rodd, 2003; Speer, 2008), my interest lies in an interaction-orientated concept of student engagement, in the sense that an instructor is able to engage students in the content of the lecture from moment-to-moment as the lecture unfolds. In this dissertation, I draw on writing studies to begin my investigation of student engagement in undergraduate mathematics lectures, namely, the work of Hyland (2001, 2005), who defines engagement as an "alignment device" used to "acknowledge and connect to others" (2005, p. 176). This definition, and the concept of student engagement, will be discussed in greater detail in the chapters that follow (see Chapters 3 and 4).

My doctoral study focuses on a multimodal investigation of student engagement in the undergraduate mathematics lecture classroom from a teaching perspective and the teaching practices enacted by university mathematics instructors in this context. The study aims to develop a deeper understanding of the phenomenon of student engagement in the chalk talk context, what it entails, and what verbal and nonverbal discursive strategies university instructors use to facilitate student engagement in mathematics lectures. Through analysis of quantitative survey data collected from student respondents (SRs) and qualitative data collected from semi-structured interviews with university mathematics instructor participants (IPs), video recordings of university mathematics lectures, and field notes produced during classroom observations, the study explores students' and instructors' discursive constructions of engaging teaching and the ways in which instructors facilitate student engagement in undergraduate mathematics lectures.

The overarching research questions that guide the study are:

1) What constitutes student engagement in the university mathematics lecture and how can it be defined?
2) What strategies do university mathematics instructors use to help realize student engagement in mathematics lectures?

To respond to the research questions, I adopt a combined theoretical and analytical framework, which draws on applied linguistics and discourse studies (Hyland, 2001, 2005; Miller, 1984, 2015; Swales, 1990), Vygotskian sociocultural theory (Vygotsky, 1962/2000), situated learning (e.g., Lave & Wenger, 1991, Rogoff, 1990), multimodality (Norris, 2004, 2011, 2013; Räisänen, 2015), speech theory (Austin, 1975; Bavelas, Coates, & Johnson, 2002; Huckin, 2002), and gesture studies (e.g., Kendon, 2004; Ladewig & Bressem, 2011), and apply it to the study of university mathematics teaching as a complex discursive practice. The combined framework is described in Chapter 2, following section 1.1, which presents an overview of the dissertation.

1.1 Overview of the Dissertation

There are ten chapters in this dissertation including this introductory chapter. Chapter 2 presents the theoretical and analytical framework of the study. Chapters 3 discusses the phenomenon of student engagement by describing the foundational schools of thought and two main approaches underlying current definitions of the phenomenon as well as new developments in student engagement research. The chapter concludes with a discussion of engagement in written discourse. Chapter 4 presents a review of research literature on student engagement in elementary and secondary school contexts, students' transition to post-secondary education, approaches to learning in the university lecture context, and student engagement in STEM disciplines and concludes with a review of research on university mathematics teaching and student engagement in university mathematics lectures. Chapter 5 describes the research design, methods of data collection and analysis, and trustworthiness of the study. Chapter 6 presents the results of the survey portion of the study.

Chapters 7, 8, and 9 present and discuss the findings of the study. The research study has amassed a large corpus of video recordings of university mathematics lectures; in this dissertation, I limit the discussion of findings to only those that are directly relevant to my research questions. The three chapters begin by presenting the definition of student engagement in university mathematics lectures that resulted from the present research and factors within the classroom context that impact student engagement (Chapter 7), followed by a discussion of the use of various teaching technologies in university mathematics teaching (Chapter 8), and conclude by describing instructors' strategies for facilitating student engagement in university mathematics lectures (Chapter 9). The conclusion, Chapter 10, presents a summary of the study and its key findings and discusses the limitations and implications of the research. The final section of the dissertation presents directions for future research.

Chapter 2: Combined Theoretical and Analytical Framework

A number of theoretical and analytical perspectives inform the research study presented in this dissertation, namely, discourse studies, including Bakhtinian concepts of utterance and addressivity, and genre theory (Devitt, 1991; Miller, 1984, 2015; Swales, 1990; Hyon, 2018), and concepts derived from Vygotskian sociocultural theory including theories of situated learning, collaborative problem-solving (Vygotsky, 1987; Lave & Wenger, 1991; Rogoff, 1990) and mediated action (Vygotsky, 1967/2000; Scollon, 1998, 2001; Wertsch, 1991). While there are multiple meanings of the word "theory" (see Abend, 2008, pp. 177-182), I draw on these theories as explanatory of particular social phenomena relevant to this research. The study adopts a multimodal approach to inquiry by drawing on concepts from multimodal (inter)action analysis (Norris, 2004, 2011, 2013), speech-act theory (Austin, 1975; Bavelas, Coates, & Johnson, 2002; Huckin, 2002), and gesture studies (e.g., Kendon, 2004; McNeill, 1992). Such perspectives, supported by reference to relevant scholarly literature and existing theory, provide the concepts used for studying a phenomenon of interest (Laberee, 2019). In other words, they constitute the combined theoretical and analytical framework of my study. A combined theoretical and analytical framework usually includes analytic models that are relevant to the research inquiry and compatible with the concepts and existing theory of the framework (Grant & Osanloo, 2014; Laberee, 2019). Such a combined framework provides the structure to define the theoretical, methodological, and analytical approach of the research study (Grant & Osanloo, 2014, p. 13), connects the researcher to existing knowledge (Laberee, 2019, para. 2), and presents a lens through which the entire study may be viewed (Creswell & Plano Clark, 2011, p. 10). The theories and concepts that make up the combined framework for the current study are presented and discussed in the sections that follow.

I begin my theoretical discussion with the concepts of *typification* and *habitualization* originally proposed by Schutz (1967; Schutz & Luckmann, 1973) and later developed by Berger and Luckmann (1967) in their theory of social constructionism. These concepts relate to the socially constructed beliefs and values and ways of understanding how to be and act in the world. Typifications, according to Schutz (1967), are derived from our knowledge and understanding of actions based on situations we perceive as *similar* (i.e., having previously occurred). Bazerman (2003) explains that typification is the process of moving to standardized forms of recognizable and easily understood action (p. 462) based on the "socially defined and shared recognitions of similarities" (Bawarshi & Reiff, 2010, p. 219). That is, individuals understand, recognize, and, therefore, infer meaning from previous direct experiences and thus, can act appropriately according to social norms and expectations. This process is maintained, in part, through the process of habitualization to which all human activity is subject (Berger & Luckmann, 1967, p. 70). Essentially, when an action is repeated frequently (in similar situations), a pattern is formed, and the meanings involved in performing the action become embedded in routine. The process of habitualization helps individuals identify and respond appropriately to recurrent social situations. These ideas are foundational to the Bakhtinian concepts of *utterance*, *genre*, *dialogism*, and *addressivity* upon which many theories of discourse and learning, discussed later in this chapter (Sections 2.2 and 2.3), are based and which are fundamental to the understanding of chalk talk as an "umbrella" genre. In the next section, I present a brief explanation of these concepts.

2.1 Bakhtinian Notions of Utterance and the Chain of Communication

Bakhtin (1986) defines utterance as a "link" in the chain of communication (p. 91) where each utterance occurs *in response* to an earlier utterance and will itself evoke a response *infinitum*. Bakhtin describes humans as participants in specific social spheres of activity he calls "sphere[s] of communication" (p. 91). As participants within social spheres of activity (i.e., acting), humans are *social actors* participating in society. Social actors participate in these spheres through language in the form of spoken or written utterances. While each utterance is individual, each social sphere develops its own habitualized (cf. Schutz, 1967), "relatively stable types" of utterances, or "speech genres" (Bakhtin, 1986, p. 60). To each sphere of activity there belongs a repertoire of speech genres that fit the views, beliefs, and shared goals of the community. Thus, our ways of making meaning are socially embedded in spheres of human activity and always situated within the chain of communication, that is, an utterance is always created in response to other, past expressions, and, in turn, in anticipation for the speech of others. The social embeddedness of utterances, in this way, is the foundation of Bakhtin's notion of dialogism-- the linking of utterances in the formation of a dialogic chain which entails that every utterance is *directed to* someone and thus includes the quality of addressivity. A speech genre, shaped by and for specific social spheres, adheres to certain expectations surrounding a typical addressee, which in part defines it as an (oral or written) speech genre[3] (pp. 94-95).

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[3] More recently the term "discourse genre" has been used to refer to genres of communication (Miller & Kelly, 2016, p. 269).

2.2 Theories of Genre

In common parlance, the term *text* is used to refer to a piece of writing or written utterance. Traditional approaches to genre view genre as stable *text types* characterized by their textual regularities, that is, as classifications of written texts categorized according to static surface-level forms and features (for a detailed history of traditional approaches to genre see Bawarshi & Reiff, 2010). More recently, and across various areas of study, a text is understood as a unit of discourse. In this sense, a text can involve multiple meaning-making means and thus may be written, spoken, and/or enacted instantiations of communicative action. Bakhtin's (1986) work was influential to the understanding of genres not as types of literary texts but as ways of *doing things* in the social world, which, over time, have become typical (cf. Schutz & Luckmann, 1973) or recognizable (Miller, 1984; see also Bawarshi & Reiff [2010] on the evolution of genre studies). Examples of non-literary genres include resumes, tax forms, recipes, newspaper articles, and more recently, personal blogs (e.g., Pinjamaa, 2016), selfies (e.g., Zappavigna & Zhao, 2017), and so on. Various schools of thought have developed around this understanding of genre, two of which are most relevant to my research on university mathematics lecturing. These are Rhetorical Genre Studies (RGS), which views genre as a rich analytical tool for studying academic, workplace, and community contexts (e.g., Devitt, 1991; Paré, 2000; Schryer, 1993; Smart, 1999), and the English for Specific Purposes (ESP) genre approach (Swales, 1990), which informs a growing body of work focused on the teaching and learning of disciplinary genres at the post-secondary level. The next section introduces RGS and the notion of genre as social action (Miller, 1984, 2015), followed by a discussion of the ESP genre approach in more detail, including the Swalesian ESP rhetorical move-step genre analysis.

2.2.1 Rhetorical Genre Studies (RGS)

North American (or New Rhetoric) genre theory, more recently referred to as Rhetorical Genre Studies (RGS), was founded by Miller (1984) whose seminal article "Genre as social action" put forth a definition of genre centred not on the form or substance of a text (as in understandings of literary genres) "but on the action it is used to accomplish" (p. 151). By drawing on theorists from rhetorical criticism (Bitzer, 1968; Black, 1965; Burke, 1951; Campbell & Jamieson, 1978) and social phenomenology (Schutz, 1967; Schutz & Luckmann, 1973), Miller (1984) developed an understanding of genre "as typified rhetorical actions based in recurrent situations" (p. 159). In line with Bakhtin's (1986) notion of utterance, RGS views genres as always responding to (our construal of) recurrent social situations. As these responses recur, they become typified and recognizable and thus help users of genres to "account for the ways we encounter, interpret, react to, and create particular texts" (Miller, 1984, p. 151) (for a more detailed history of the foundations of RGS see Artemeva & Freedman, 2008, 2015). Another key component of the RGS perspective is the notion of *exigence* (Miller, 1984; cf. Bitzer, 1968). Miller (1984) describes exigence as an "objectified social need" (p. 157) or motive that "provides an occasion, and thus a form, for making public our private versions of things" (p. 158). By responding to a need, or exigence, the social action itself calls for a rhetorical response and in this way "genre not only responds to but also *constructs* recurring situations" (Devitt, 1993, p. 578; emphasis added).

Since the notion of genre as social action was proposed by Miller (1984), scholars of RGS have used the concept to investigate written genres within various professional and academic contexts including recording keeping in social work (Paré, 2000), reports by tax accountants (Devitt, 1991), and the sketchbooks of architecture students (Medway, 2002). Genre researchers have found rhetorical genre theory useful for investigating how genres are used by individuals in particular professions to do their work and how those genres are connected and used together as *genre sets* (Devitt, 1991) to accomplish professional tasks. Devitt introduced the concept of the genre set to describe the multiple genres used by a particular professional community to accomplish professional tasks by investigating the genres tax accountants use to do their work. Devitt observed that in professional contexts, many different but related genres are used by individuals in particular professional roles to fulfill the requirements of their positions. These genres are distinct, but all are connected, and related to the work of the professional community. Thus, genre sets are "bounded constellations of genres" (Bawarshi & Reiff, 2010, p. 88), connected the individual in the professional role who uses them and the task(s) they are used to achieve. Particularly relevant to the present study, is research by Bazerman (2004) who describes the genre sets of a classroom, that is, the genre set used by the instructor (e.g., writing the syllabus, preparing teaching notes, replying to student questions, designing lesson plans, etc.), and the genre set used by the students (e.g., taking notes in class, writing essays, preparing study notes for exams, emailing the instructor, etc.). By producing these texts, the individuals perform the genres related to the work required of their professional (or academic) roles, and these genres respond to, and construct recurrent situations, that in turn call for a response. For example, the instructor of a course writes a syllabus to distribute to the students in class, later at home a student reads the syllabus and emails the instructor with a question about an assignment described in the syllabus, the instructor replies to the email and the next day in class she responds publicly to the student's question in case other students also share the same question, the students write down the information in their notes, and so on. Thus, the instructor produces genres which prompt the students to produce genres in response; the set of genres used by the instructor differs from the genre set used by the students but the distinct genres belonging to the two sets interact. Some of the genres are written (e.g., the syllabus, notes, and emails) and some are spoken (e.g., responding to student questions).

In addition to written genres, RGS has been used to investigate genres that are *enacted* to respond to (and construct) recurring social situations. In an overview of key concepts in RGS, Artemeva (2004) highlights the notion of *nontextual utterance* proposed by Voloshinov (1930/2000). In his analysis of the "non-verbal" (implied) part of the utterance, Voloshinov (1930/1983) noted that "every utterance is composed in effect of two elements: a *verbal* and a *non-verbal* part" (p. 124, emphasis in original; as cited in Artemeva, 2004, p. 21), and provides examples of scenarios in which individuals use verbal and nonverbal utterances in typified (cf. Schutz & Luckmann, 1973) and recognizable ways. A modern example that captures the essence of Voloshinov's concept might be a scenario in which a cashier at a coffee shop asks a patron for their name while holding a pen to an empty cup. In this scenario, the patron understands that the cashier wants to identify the cup with a name so that the barista can later call out the name when the coffee is ready to be picked up, and is not simply asking out of curiosity. Thus, the cashier's utterance includes a verbal and a non-verbal part. Voloshinov (1930/1983) concludes that there are three main factors that affect the nonverbal part of an utterance: the time and place (spatial-temporal context), the theme (subject) of the utterance, and the speaker's attitude to what is happening (p. 125). Artemeva (2004) explains that in doing so, Voloshinov "inextricably links" the meaning of the utterance to the spatial-temporal context in which it occurs.

To return to genres of communicative behaviour (or *enacted* genres), in addition to studying how various genres function to accomplish the goals of particular organizations (e.g., Paré & Smart, 1994; Smart, 1999), or the sets of genres that are used by individuals performing particular roles in particular professional or academic contexts (e.g., Bazerman, 2004; Devitt, 1991), RGS scholars have investigated the ways that certain spoken genres are enacted as part of professional learning and identity construction. For instance, Spafford, Schryer, Mian, and Lingard (2006) describe the medical case presentation (wherein medical students report patient information to their physician mentors and medical teams) as a school-work hybrid that "conveys to medical students ways of speaking, thinking, perceiving, and behaving that will shape their future identities as physicians" (p. 125). Thus, the medical case presentation is a spoken genre, enacted by novices as they learn to behave in ways that reflect the professional role of physician (see Schryer, Campbell, Spafford, & Lingard, 2008). Other enacted genres that have been investigated from the RGS perspective include the professional genre of televised political interviews (Freadman, 2015), and most relevant to my study, the embodied pedagogical genre of university mathematics lecturing (e.g., Artemeva & Fox, 2011; Fogarty-Bourget, 2013; Fox & Artemeva, 2012). Artemeva and Fox (2010, 2011; Fox & Artemeva, 2012) identify chalk talk as a genre, enacted through speech, writing and movement, used by university mathematics instructors to teach mathematics to undergraduate students (discussed further in Chapter 4, Section 4.4). In this dissertation, I depart from Artemeva and Fox's (2010, 2011) and Fox and Artemeva's (2012) definition of chalk talk as a single genre and consider it as an umbrella genre, overarching a set of subgenres (cf. Devitt, 1991), enacted through various ways of making meaning, that is used by university mathematics instructors to perform the work of their profession (i.e., to teach university mathematics to students). These concepts are discussed in more detail in later sections of the dissertation (Sections 2.4 and 4.4). In the next subsection, I discuss the ESP genre approach.

2.2.2 Swalesian ESP rhetorical move-step genre analysis

Genres in ESP are viewed as oral or written text types, or “communicative events,” characterized by their social function, or “communicative purpose” (Swales, 1990, p. 58), which is reflected in their content and form (structure, style, lexical choices, etc.). According to Swales (1990), genres act as *communicative tools* used by individuals belonging to a social group to accomplish goals within certain social contexts. Similar to Bakhtin’s (1986) notion of spheres of communication, Swales refers to these social groupings as *discourse communities* and describes them as “sociorhetorical networks that form in order to work toward sets of common goals” (Swales, 1990, p. 9). Within these contexts, genres act as a means with which to fulfill the communicative purposes necessary to accomplish the shared goals of the community.

Swales (1990) provides six defining characteristics necessary for identifying a social group as a discourse community: (1) there exists a broadly agreed upon set of common public goals which can either be explicitly stated or tacitly understood; (2) there are "mechanisms of intercommunication" among members such as meeting rooms, emails, newsletters, etc., in order to achieve and/or further common goals; (3) these mechanisms are used primarily to provide information and feedback; (4) the discourse community utilizes and hence possesses one or more genres in the communicative furtherance of its aims and (5) in addition to the genre(s), the community has acquired a "specific lexis" which can take the form of shared and specialized terminology; finally, (6) there are a threshold level of members with a suitable degree of relevant content and discoursal expertise (experts) who can pass on knowledge of goals and practices to novice members (pp. 24-27). Many of the above characteristics can be identified, for example, within the global community of university mathematics lecturers (see Artemeva & Fox, 2011). For example, there exist mechanisms of communication (e.g., emails, conferences, academic journals[4], seminar sessions[5], etc.) used to provide information and feedback between members; the umbrella genre of chalk talk exemplifies a set of communicative subgenres used to further the aims of group members (see Chapter 4, Section 4.4 for further discussion); there is quite obviously a specific lexis of mathematics terminology and symbolism (see O'Halloran, 2005); and finally, the group members are made up of expert instructors who can pass on knowledge to new student-members (i.e., novices). Drawing on Swales (1990), McGrath and Kuteeva (2012)

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[4] See McGrath and Kuteeva (2012) who, following Hyland (2005), conducted a textual analysis of pure mathematics research articles.

[5] For a detailed explanation of the professional mathematics seminar as an important mechanism for communication in the discourse community of university mathematics lecturers see MacKenzie and Barany (2014).

identify the *mathematical discourse community* (cf. Artemeva & Fox, 2011) whom they describe as “a ‘tribe’ with a set of established conventions and understandings shared by community members” (p. 171). Thus, in accordance with the work of Artemeva and Fox (2011) and McGrath and Kuteeva (2012), the concept of discourse communities may be usefully applied to a study of university mathematics lecturers.

As mentioned earlier, rhetorical move-step analysis (Swales, 1990) is ESP’s approach to genre analysis. Defined in relation to a discourse community’s shared goals, Bawarshi and Reiff (2010) suggest, “it is *communicative purpose*… that gives rise to and provides the rationale for a genre and shapes its internal structure” and, therefore, ESP often takes the communicative purpose of a text as a starting point for genre analysis (p. 46; emphasis added). In sum, once a genre within a particular discourse community has been selected, an ESP genre analysis will begin by defining the communicative purpose of the genre. From there, the organization of the text is examined in terms of the rhetorical *moves* (also referred to as macro-structures), that is, sections of the text that aim to accomplish their communicative sub-purposes. These rhetorical moves are then further analysed in order to examine the *steps* (also referred to as micro-structures) through which the move is realized, and their linguistic and textual features (see Hyon, 2018; Swales, 1990, 2004). By analysing academic disciplinary genres in this way, Swalesian move-step analysis can help researchers understand a) how a text fulfills its communicative purpose, if at all, and b) the ways in which the textual and linguistic features of that text work to accomplish its aim, while still attending to the broader context in which the genre is situated and the discourse communities to which is belongs.

2.2.3 RGS and ESP: A comparison

Many similarities exist between ESP and RGS, for example, both approaches recognize genres as situated rhetorical actions and both acknowledge the complex and dynamic relationship between text and context (Bawarshi & Reiff, 2010, p. 54). However, there are also notable differences between the two schools of thought. From an ESP perspective, genres are described as communicative tools situated *within* social contexts[6]. From an RGS perspective, the concept of "*inter*play and *inter*action" (Freedman & Medway, 1994, p. 9; emphasis in original) between genre and context is central (Devitt, 1993; Freedman, 1993) where genres are seen as responding to recurrent situations (Miller, 1984, 2015) while simultaneously shaping the situations to which they respond (Bawarshi, 2000; Miller 1984; Paré & Smart, 1994). Thus, RGS scholars view genres as *both* "the situation *and* the textual instantiation of that situation" (Bawarshi, 2000, p. 357; emphasis added). So, to return to my earlier point, because ESP scholars view genres as communicative tools situated *within* social situations, social contexts are seen as providing "valuable *background* knowledge" about discourse communities and communicative purposes (Bawarshi & Reiff, 2010, p. 54; emphasis added). RGS scholars, on the other hand, see genres as responding to social situations and also *creating* social situations that elicit responses and so on (as is the case in the example provided

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[6] As mentioned, this perspective stems from the ESP understanding of genres as classes of "communicative events" characterized by shared "communicative purposes" and patterns of "structure, style, content, and intended audience" (Swales, 1990, p. 58). These shared purposes "and the *role* of the genre within its *environment* give rise to specific textual features" (Freedman & Medway, 1994, p. 7; emphasis in original).

above, in Section 2.2.1, of the instructor and students producing genres related to their work). Thus, from an RGS perspective, text and context are bound together in a way that cannot be teased apart. Another aspect that influences the RGS approach to teaching and learning genre is the perception of genres not as stable text-types, but as “complex” and dynamic “discourse practices” (Schryer, 1993, p. 208). For instance, the genre of the medical case presentations (Schryer et al., 2008; Spafford et al., 2006) (discussed in Section 2.2.1) is a complex, professional discursive practice enacted by medical student practitioners as part of their apprenticeships in becoming professional physicians. The case presentations involve written notes and spoken presentations of patient information, but, as technology develops, the genre may evolve to include visual information (perhaps presented on laptops or tablets) or Skype calls to involve members of the medical team practicing at a distance. Neither written nor enacted genres remain fixed or static, rather, genres are inherently social, evolving and changing as society advances. Schryer (1993) develops Bakhtin’s (1986) notion of “*relatively* stable types” of utterances (p. 60; emphasis added) further, describing genres as “stabilized-for-now or stabilized-enough sites of social and ideological action” (p. 208). The recognition of the dynamism of genres and genre conventions is yet another defining feature of the RGS approach to genre studies.

While it is important to note these foundational differences between ESP and RGS, the similarities that exist between the two schools are such that many of the notions are complementary, and can be used in coordination with each other, when appropriate. In this dissertation, I use the notion of discourse communities and the rhetorical move-step analysis (Swales, 1990) in my investigation of the teaching practices used in chalk talk lecturing, but my understanding of chalk talk as a multimodal, embodied umbrella genre made up of actions[7] that are recurrent and recognizable (i.e., have become typified), is firmly planted in the RGS tradition. In addition, the concepts of learning and participation I draw on, discussed in the next section, are also compatible and complementary to RGS (see Artemeva, 2008).

2.3 Guided Learning and Active Participation

According to Vygotsky (1987) much of the learning involved in child development and the development of their higher-level cognitive functioning is social in that it occurs through societal interaction. This is the foundational principle of Vygotsky's sociocultural theory of development; children come to know and understand how to be in the world largely through interaction with members of their cultural community (e.g., adults, siblings, teachers, and peers) and environment, and so, child development should be considered in the sociocultural historical context. While studying how children learn through participation in activity (i.e., through doing), Vygotsky and his colleagues observed that children were capable of more advanced learning when assisted by adults or more capable peers. He explained that when acting alone, a child is capable of completing tasks corresponding to their actual level of development, however, when accompanied by an adult or more capable peer to provide scaffolding (support

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[7] Such typified actions include instructors of chalk talk lectures writing on the board while articulating what is being written, turning to the students in the classroom and talking about what has been written, gesturing to students, asking questions, referring to notes, and so on (see Artemeva & Fox, 2011, pp. 11-12).

tailored to the child's level of development), the child is able to complete more advanced tasks than would be possible alone. It is this discrepancy between a child's actual level of development (what the child can accomplish independently) and the level that can be reached with assistance that Vygotsky (1987) defines as the Zone of Proximal Development (ZPD) (p.187). According to Vygotsky, learning *leads* development, and so the most beneficial learning is that which is in advance of the (actual) mental (cognitive) level of the child. Thus, providing opportunities for supported learning that marches slightly ahead of development (provided it is within the realm of the ZPD) leads learning, and feeds development forward.

Heavily influenced by Vygotskian notions of development, situated learning is a perspective that views learning as context-bound and occurring through learners' active participation in ongoing social activities (e.g., Lave & Wenger, 1991; Rogoff, 1990). Guided participation, developed by Rogoff (1990), is an analytical perspective on a particular situated learning scenario which describes the learning process that occurs when instructors challenge, constrain, and support learners in the process of posing and solving problems (i.e., tasks or activities designed or selected by the instructor for the purpose of learning [cf. Lave & Wenger, 1991]) while learners observe and actively participate at a "comfortable but slightly challenging level" (Rogoff, 1990, p. 18). This type of situated learning focuses on the learner and the guidance provided by the instructor *and* the active participation of the learner is viewed as necessary for learning. Rogoff explains that these "processes of interpersonal communication and shared participation in activities inherently engage children and their caregivers and companions in stretching children's understanding and skill" (p. 19). While Rogoff (1990, 2003) focuses primarily on children’s learning, such guided participation occurs with learners of all ages in various educational settings including classrooms, online platforms, and training facilities (see Artemeva et al., 2017 on situated learning in medical education). As shown later in Chapter 4, the notions of guided learning and active participation inform a significant portion of the research literature on mathematics teaching. These concepts echo notions of scaffolding (Wood, Bruner & Ross, 1976) and ZPD (Vygotsky, 1987) in that the guidance provided to the learner by the caregiver/teacher helps to advance the skills and knowledge of the learner so that she will be able to operate independently in the future (Freedman & Adam, 1996, p. 398). The ways that instructors and learners interact with each other can be theorized in terms of mediated action (Vygotsky, 1987) which is discussed in the following section.

2.4 Mediated Action and Multimodal Meaning-making in Interaction

A recurrent theme that runs through many of the theories of interaction and meaning-making is that of the mediated action (Vygotsky, 1987). Vygotsky theorized that much of human activity, including the ways that individuals interact with each other and the social world, is mediated through cultural tools and signs. These can include language, symbols, bodily expression, and other systems of behaviour also referred to as mediational means (Wertsch, 1991, p. 12; Vygotsky, 1987). When using mediational means to participate in social activity, we do so through mediated action (Vygotsky, 1987; Wertsch, 1991). The mediated action is central to Scollon’s (2001) mediated discourse theory which is concerned with “social actors *as they are acting*”, that is, the instances in which their discourses are “instantiated in the world as social action, not simply as material objects" (p. 3, emphasis in original; see also Austin, 1975). In saying this, Scollon (2001) emphasizes that social action is grounded in social actors and objects, and thus inextricably linked to discourse[8]. According to Scollon, mediated actions are "carried out through material objects in the world (including the materiality of the social actors – their bodies, dress, movements)" (p. 4), in other words, mediational means (or cultural tools) are ways of conveying communicative meaning (through speech, writing, gesture, and so on). From the perspective of mediated discourse theory, mediational means (ways of conveying meaning) are always multiple in the production of any single social action. Therefore, when social actors participate in discourse(s) (i.e., communicate through social action), they do so through multiple ways of making meaning, also known as *modes*. This is, in essence, the central concept of multimodality (Jewitt, 2002, 2005; Kress & van Leeuwen, 1996/2006, 2001; Norris, 2004, 2011). As social actors participating in society, we communicate using multiple modes (ways) of meaning-making including speech, gesture, writing, movement, facial display, gaze directionality, art, clothing, silence, and so on. We use such communicative modes *together* (i.e., speech with silence, movement with gesture, gaze directionality with facial display, writing with font and blank space, etc.), and thus they are always *multiple* in the production of any mediated action.

On the basis of Scollon's (1998, 2001) work, Norris (2004, 2011) developed the multimodal (inter)action analysis framework (MIA), for the study of human interaction.

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[8] Following Gee (1999), Scollon differentiates between *discourse* (with a little "d"), to refer to language-in-use, and *Discourse* (spelled with a capital "D") in the broader, sociohistorical sense. This distinction is beyond the scope of my dissertation.

Norris uses parenthesis around “inter” in order to emphasize the idea that all actions are interactions. Norris (2014b) explains that even when an individual acts alone, she always acts with or through multiple and multimodal “physical and cognitive/psychological/embodied/socio-cultural mediational means as they interact with objects and the environment” (p. 184). In her earlier work, Norris (2004, 2011, 2012) presents MIA as a methodological framework for the analysis of human (inter)action, and later refers to multimodal mediated theory (2013) as the theoretical framework behind MIA. In subsequent publications the focus returns to MIA, or “multimodal mediated (inter)action analysis” (Norris, 2014b, p. 182), as both a theoretical and methodological framework (Norris, 2014b, 2015), or analytical approach (Norris & Makboon, 2015; Norris, 2014a). While the terminology may still be in the process of development, multimodal mediated theory and MIA are nonetheless extremely useful contributions to multimodal theory and research. In this dissertation, multimodal mediated theory is described as the theoretical framework that informs the methodology MIA as described by Norris (2013); however, as the most widely recognized referent, MIA is used to refer to the whole of Norris’s developing framework.

The concept of “mode” in Norris’s MIA framework stems directly from mediated discourse theory (Scollon, 1998, 2001; Wertsch, 1991) and essentially Vygotsky (1987), wherein Norris (2013) defines a “mode”[9] as a *system* of mediated action (p. 278) with rules and regularities attached. Norris explains that modes can be described on a continuum from concrete to abstract. To illustrate, Norris provides the examples of

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[9] Norris’s (2004, 2011) definition of mode differs from the definition of mode as a semiotic resource (Halliday, 2004; Kress & van Leeuwen, 1996/2006, 2001).

language and walking. Language is an abstract system of mediated action, it has many rules and regularities attached to it that have become embedded in the cultural tools of semantics and syntax, for instance. Walking is a more concrete system of mediated action, the way it is recognized is highly constrained by the body (pp. 278-280). Thus, on the continuum of concrete to abstract, walking is on the end of the concrete, whereas language is on the end of the abstract. The rules and regularities of walking are more attached to the social actor, whereas the rules and regularities of language are more attached to the mediational means. Norris explains that these systems of mediated actions, through their habitual use and sociocultural embeddedness, become recognizable, and thus meaningful, ways of acting in the world. The rules and regularities of a mode, which may be more attached to the mediational means or more attached to the social actor (p. 277), both constrain and enable users in their meaning-making. Essentially, we operate (i.e., do things) in society through systems of action mediated by various means (for example, language systems, writing systems, systems of movement); these systems of mediated action (as Norris defines modes) are recognizable and thus meaningful. Following Scollon (2001), Norris (2013) suggests that talking about modes in this way allows researchers to remain focused on the social actor, while still acknowledging the mediational means and sociocultural and historical contexts in which they come together to make meaning.

MIA is often used to investigate shifts in the attention and awareness of social actors by analysing the levels of *modal complexity* and *modal intensity* (Norris, 2004, 2011) used by social actors as an interaction unfolds (e.g., Norris, 2016; Pirini, 2014). Norris defines modal complexity as referring to the intertwining of multiple modes in the production of an action. Take for example, a conversation between two people. A conversation that takes place face-to-face involves the convergence of modes such as speech, gaze, gesture, facial display, proxemics, and, occasionally, touch, all of which are deployed simultaneously. The integration of these modes together in the formation of a meaningful whole results in modal complexity. By comparison, a conversation that takes place over the telephone involves the convergence of fewer modes (namely, speech and silence) meaning that there is less modal complexity employed in the construction of the interaction. Modal intensity, on the other hand, refers to the relative strength, weight, or importance of a particular mode (Norris, 2004a; Pirini, 2014), or more specifically, heightened pragmatic salience occurring as a result of an action being made prominent relative to surrounding or co-occurring actions (Fogarty-Bourget, 2018; Fogarty-Bourget, Pirini, & Artemeva, n.d.). To return to the example above, while the conversation that takes place over the telephone may not have high modal complexity, the mode of speech is of primary importance and thus features of speech, such as pausing for instance, can take on greater intensity. Within the MIA framework, modal complexity and modal intensity are the two components of modal density, a conceptual tool for analysing the degree of attention and awareness of social actors in interaction. High modal density can be achieved through the use of high modal complexity, or high modal intensity, or both high complexity and intensity. The more complex or intense the modes of communication are (i.e., the higher the modal density), the more attention a social actor pays to the action(s) being produced (Norris, 2004). In other words, high modal density becomes a locus of attention in interaction. In the MIA framework, a distinction is made between attention, which is at the forefront of an actor's focus, and *awareness,* which is backgrounded. Social actors are cognizant of actions with lower modal density but may not attend directly to them. Such a distinction is beyond the scope of this dissertation; thus, I focus primarily on what social actors are clearly attending to (made evident by bodily orientation, gaze directionality, speech addressivity, etc.).

MIA (Norris 2004, 2011) operates on the premise that mediated action is inherently social; it is mediated by multiple mediational means or cultural tools (Scollon, 1998, 2001; Wertsch, 1991; see also Vygotsky, 1987) and thus corresponds to the sociocultural perspective and complements the theories of genre and learning discussed in the previous section. In this dissertation, I draw on MIA to inform my understanding of multimodality as well as my analytical approach. In particular, I use the concept of modal density as a locus of attention in interaction and use Norris's (2004, 2011) notion of units of mediated action in my coding of multimodal data (discussed in further detail in section 5.6.2). In the subsections that follow, I discuss the work of other theorists who inform my combined theoretical and analytical framework such as Goffman (1967) and Austin (1975) whose research focuses on meaning-making in spoken and face-to-face conversation. I also draw on the work of scholars who focus on such nonverbal aspects of meaning production as silence (e.g., Huckin, 2002) and gesture (Kendon, 2004). These concepts form the basis of scholarly understandings of human interaction to date, including interaction in educational contexts.

2.4.1 (Un)focused interactions and giving(-off) information

Famously, Goffman (1959, 1963) explored the nature of social interaction in everyday life including the ways that individuals co-construct meaning and notions of self and identity. Goffman's work was extensive and influential to many scholars of the social sciences, particularly those interested in face-to-face interaction and communicative behaviour (e.g., Kendon, 2004; Sacks, Schegloff, & Jefferson, 1974; Tannen, 1993; Watzlawick, Beavin, & Jackson, 1967). Most relevant to my study is Goffman's explanation of intentionality in meaning-making. Goffman (1959) explains that as actors on a social stage (i.e., social actors participating in society), we intentionally *give* information about our feelings, intentions, and identities. However, even without intentionally communicating, individuals when in co-presence, implicitly *give-off* meaning as soon as they are perceived by another individual. This has also been described by Watzlawick, Beavin, and Jackson (1967) as the impossibility of not communicating, where simply by being visible, there exists a "very basic interpersonal flow of 'information'" between individuals in co-presence (p. 48; see also Andrén, 2014, p. 159). As social actors, we always "read-off" meaning (Norris, 2016, p. 151) from objects, the environment, and actions occurring around us, even if they are not explicitly produced for the purpose of communication. Andrén (2014) describes such implicit actions as having low communicative explicitness, that is, they communicate meaning simply as a consequence of being in a shared space with another individual in what Goffman (1963) calls an *unfocused* interaction. Unfocused interactions occur when individuals are co-present but not involved in a cooperative communicative exchange (e.g., several students working silently in a shared study space with other students seated nearby). *Focused* interactions, on the other hand, occur when individuals are co-present and cooperating in a shared communicative exchange (e.g., several students brainstorming together about ideas for a group project). Focused interactions can be initiated through touch, talk, bodily orientation, "or by briefly establishing mutual gaze"

(Andrén, 2014, p. 160) and are maintained via sustained mutual communicative activity. All actions produced during focused interactive encounters are more communicative by virtue of being framed by a focused interaction and as such are more likely to be noticed (or presumed to be noticed) and responded to than actions performed in unfocused interactions (Andrén, 2014; Goffman, 1963; see also Bavelas, Coates, & Johnson, 2002 on the reciprocity of face-to-face dialogue). It is important to note that "meaning is always co-constructed", as Norris (2004) points out, "and unintentional actions may be just as communicative as intentional ones" (p. 33). Furthermore, even if we intend our actions to communicate meaning, there are always discrepancies between what we say, what we mean, and what is understood; these are the key concepts of Austin's (1975) speech-act theory.

2.4.2 Speech-acts and silence

As a philosopher of language, Austin was primarily interested in meaning production and function of the spoken utterance, in particular, the way in which by saying something (i.e., producing a spoken utterance) the social actor is "doing something" (Austin, 1975, p. 12). Speech act theory (Austin, 1975), however, is useful from a multimodal perspective as well as it allows researchers to account for the spoken content of an utterance as well as the pragmatic and contextual elements which contribute to meaning construction such as, for example, gestural and prosodic cues. Speech act theory differentiates between the *locutionary* and *illocutionary* force of an utterance. The locutionary force of an utterance represents the literal meaning of what is said, whereas the illocutionary force represents the communicative meaning of the utterance (i.e., the effect the utterance is intended to have on the listener). Speech act theory also attends to the *perlocutionary* effect of an utterance which is the way the utterance is taken up by a recipient. For example, if a mathematics instructor exclaims during her lecture that it is getting very loud in the classroom, the locutionary act would be the statement "it is getting very loud in here", whereas the illocutionary act might be a request for students to be quiet and pay attention. If the students reacted to the utterance by becoming quiet, their silence would be an aspect of the perlocutionary effect of the instructor's utterance. Examples of speech acts include commands, requests, and invitations, however Austin distinguished between numerous different types.

Many scholars have expanded the work of Austin, most relevant to my study is the work of Huckin (2002) and Bavelas, Coates, and Johnson (2002). In his study of the deliberate omission of information relevant to a particular topic in a particular context, or textual silence, Huckin identified speech-act silences, or "active, communicative silences" (p. 348), which are used to fulfill communicative purposes through illocutionary force, as follows: (1) the speaker or writer intends the silence to be perceived as having communicative import, (2) the listener or reader can arrive at this understanding only via shared expectations, that is, only by invoking the same frame of reference as the speaker/writer, and (3) the illocutionary force of the silence can be worked out by the reader or listener using principles of linguistic pragmatics (Huckin 2002, p. 349). In addition to Huckin's notion of speech-act silences, I draw on the work of Bavelas, Coates, and Johnson (2002) who describe how listeners insert their responses into speakers' narratives by using speech, gesture, and gaze and how different types of responses perform different communicative functions. For example, non-specific listener responses, such as "yeah" and "mhm", often accompanied by nodding, are used to convey attentiveness and understanding without being designed to address what the listener is saying at the moment (p. 568). Specific listener responses, however, are tightly connected to the precise moment in the speaker's narrative by supplying relevant utterances and facial expressions. A listener who provides such a response goes beyond conveying understanding and contributes to the narrative by "briefly but frequently becom[ing] a co-narrator" (p. 569). Further, bodily resources such as gesture, gaze, and movement add to the speaker's illocutionary force as well as to the listener's contributions to a dialogue which is produced through collaborative action.

Speech act theory is vast and complex. In this dissertation, I draw only on its selected elements that allow me to account for the spoken content of the instructors' utterances as well as the pragmatic and contextual elements of utterances such as, for example, gestural and prosodic cues. Integrating genre studies with selected elements of speech act theory allows for a broad analysis of verbalized features while providing an accurate understanding of the actions performed by the speaker. To further investigate and understand the role of gestures in the multimodal umbrella genre of chalk talk I complement the combined framework of this study with gesture studies.

2.4.3 Gesture studies

Building off the work of Goffman (1963), Kendon (2004) defines utterance as "any action or complex of actions" treated by participants in an interaction as "giving information", or more specifically, "any unit of activity that is treated by those co-present as a communicative 'move', 'turn' or 'contribution'. …Such unit of activity may be constructed from speech or from visible bodily action or from combinations of these two modalities" (p. 7). Kendon's view of a speaker's utterance, which is always produced "to *achieve* something" (p. 225; emphasis in the original), is strikingly similar to the view of stabilized utterance (Bakhtin, 1986) as social action (Miller, 1984, 2015), which is foundational to RGS, and Voloshinov's (1930/1983) notion of the nontextual utterance (see also Artemeva, 2004). Therefore, Kendon's gesture theory can be seen as compatible with and complementary to RGS. Further, his research has demonstrated how gestures can be integrated into utterances in the process of meaning making to add to their (a) propositional meaning and (b) function to "do things" (Kendon, 2004, p. 225; cf. Austin, 1975). When speakers employ the modes of gesture and speech together, they achieve an "ensemble of meaning" through the attainment of "semantic coherence" between the modes of gesture and speech (Kendon, 2004, p. 108). As gesture and speech interact, a more complex coherent unit of meaning is created.

As noted by Kendon (2004), gesture is used to describe "actions that have the features of manifest deliberate expressiveness" (p.15). The production of a gesture involves a body part (generally, a hand or two hands) moving through a series of phases[10] which, from the beginning to end, constitute a gesture unit, or movement excursion (Kendon, 2004, pp. 11-12; see also McNeill, 1992). The gesture unit begins when the hand departs from the rest position, also known as the "home position" (Sacks & Schegloff, 2002, p. 137), into a stroke. The stroke is the movement of the gesture that "peak[s]" (McNeill, 1992, p. 83) or is "accented" (Kendon, 1975, p. 357), where it is sometimes held for a moment (a post-stroke hold), before returning to the rest position (recovery/retraction). The rest position is not included in the gesture unit, nor is it

[10] For a comprehensive description of articulatory features of gesture phases see Ladewig and Bressem (2011; Bressem & Ladewig, 2013).

described as carrying meaning beyond action completion and non-speakership (e.g., Dosso & Whishaw, 2012; Cibulka, 2015); rather, the meaning of a gesture is thought to be expressed by the stroke phase and any accompanying post-stroke hold (Kendon 2004, 112). In the chalk talk context, however, rest positions have been shown to play a role in student engagement when used by instructors to convey specific meanings to students in the classroom, this is discussed further in Chapter 9 (Section 9.2).

Kendon (2004) has developed a comprehensive taxonomy of gestures in-use by drawing on a large corpus of video-recordings showing speakers interacting in a variety of settings. Many excerpts of these data portray face-to-face interactions that take place in the participants' everyday lives. This rich data set, together with Kendon's more holistic interest in gesture use, has generated a categorization scheme that lends itself well to the study of human interaction. Kendon's primary interest is in gestures as they are used together with speech to create meaning; he thus makes a point of stressing that his classification system is a typology of gesture *functions* and not of gestures alone. The classification system includes specific functions of gestures as they are used in coordination with speech to create complex bundles of meaning. Broadly speaking, the taxonomy addresses the many types and uses of deictic (pointing) gestures (including pointing with the index finger and with the open hand), gestures of "precision grip", and two gesture families of the open hand (p. 225). Kendon explains that a gesture can be part of the *referential* content of an utterance, in which it provides representation of something, or, it may contribute to the *propositional* content of an utterance, in which it indicates something to be considered (pp. 160-161). Alternatively, gestures may be used for *pragmatic* functions including *modal* (used to frame how an utterance is to be interpreted), *parsing* (used to punctuate or organize the components of an utterance), and *performative* (used to indicate the kind of speech act a person is engaging in) (pp. 158-161). Kendon's (2004) typology focuses on the referential capabilities and pragmatic functions of gestures in-use. Much like Norris (2011), who uses ethnographic approaches to data collection, Kendon (2004) notes the value of investigating interactions as they occur in participants' everyday lives. I share the perspective that interactions are best understood as they take place in context and take such approaches to data collection (whenever possible) in my own research. This holistic perspective is highly valuable throughout the study design process. The following subsection discusses how the combined framework is operationalized in the research.

2.5 Operationalizing the Combined Framework: A Holistic Approach to Inquiry

Now that I have presented the combined theoretical and analytical framework of the study, the question is, how can it be productively operationalized? Or, what does it mean in the context of this study? What the combined framework offers is a holistic approach to inquiry in the fullest sense; that is, a multimodal investigation that is not limited to a particular discursive text (comprised of writing *and* images, talk *plus* nonverbal behaviour) within a particular social context, but is capable to view activity as situated social practice, involving the interaction of social actors, contexts, "artifacts, technologies, spatial arrangements, and time" (Räisänen, 2015, p. 134; see also Voloshinov, 1930/1983, p. 125). From an RGS perspective, text and context are bound (Bakhtin, 1986; Miller, 1984), where text is understood as a complex, dynamic, rhetorical action (Devitt, 1993; Miller, 1984, 2015). Drawing on Kendon (2004), I view utterance as "any complex of actions" treated by social actors as a communicative contribution (p. 7), and meaning-making as always co-constructed and occurring through multiple modes (Norris, 2004, 2011, 2013). The combined framework allows me to understand context as plural and "nested" (see Bavelas, Gerwing, & Healing, 2014, p. 3) including cultural, institutional, linguistic, social, and situational contexts. In terms of situational context, I recognize actions frozen in objects and the environment (Norris, 2004, 2011), including tools and technologies that as social actors we can control, and "external modalities that may wield power and control over our performance" such as space, layout, "weather" and "time of day" (Räisänen, 2015, pp. 134-135).

In this dissertation, I apply the combined theoretical and analytical framework to the study of the multimodal embodied umbrella genre of chalk talk lecturing. Specifically, I explore the phenomenon of student engagement as it occurs in the chalk talk lecture classroom and the rhetorical strategies used by university mathematics instructors to facilitate student engagement in this context. Using the holistic approach described above, the multimodal investigation considers contextual elements (e.g., the community of practice of university mathematics lecturers, local and institutional contexts, and learning environment) as well as the minute features of interaction that make up the teaching of a chalk talk lecture (e.g., student-instructor interactions, individual utterances, and parts of utterances such as phases of gestural actions [see Ladewig & Bressem, 2011; Bressem & Ladewig, 2013]). Note that, throughout this dissertation, I sometimes talk about different facets of a particular context (or interaction, or utterance, etc.,) as though they were separable. Similarly, I often refer to various modes as though they can be delineated and observed independently from the social actor or other co-occurring modes. I do so only for the purpose of discussion; social actors, actions, and contexts are entwined in interaction, and cannot be teased apart.

In the chapters that follow I present a review of relevant research literature. In Chapter 3, I discuss the concept of student engagement beginning with the foundational literature and philosophical underpinnings of three main schools of thought followed by a review of current definitions of the phenomenon and concluding with a discussion of engagement in written genres. In Chapter 4, I review empirical research literature of student engagement in various educational settings with a focus on post-secondary teaching contexts and university mathematics teaching.

Chapter 3: The Complex Concept of Student Engagement

As the majority of scholars who conduct and consume research on *student engagement* (sometimes referred to as *academic engagement*, *school engagement*, or simply *engagement*) are aware, there is little agreement on how the phenomenon ought to be defined. In fact, there is no clear definition shared among the majority of the publications to date. Dunne and Owen (2013), the editors of *The student engagement handbook*, note that to look up the term "student engagement" is to be met with "a confusing array of definitions and associated concepts" (p. xv). They go on to suggest that the term is used in the same breath as student participation, effort, time on task, or motivation. One reason for this confusion seems to stem from a seldom acknowledged divergence in foundational literature between two schools of thought the authors draw on. The first school of thought, referred to here as the *interactive approach*, traces its roots back to scholars of educational and cognitive development such as Dewey (1938), Freire (1998), and Vygotsky (1987). The second school of thought, which I will refer to as the *academic achievement approach*, identify "student engagement theory" as stemming from educationalists of the 1980s, including Astin (1984, 1985), Pace (1984), and later Kuh et al. (1991). This divergence has a clear impact on the way these two schools of thought frame current definitions of student engagement. I continue this chapter by introducing the philosophical underpinnings of current research on student engagement and review the conceptualizations of the student engagement phenomenon as outlined by McMahon and Portelli (2004). The chapter then attends to the two school of thought and discusses the current definitions of student engagement.

3.1 Traditional, Liberal, and Critical-Democratic Conceptualizations of Student Engagement

McMahon and Portelli (2004) critique current uses of the term "student engagement" suggesting that increasingly, over the last decade, studies that address the phenomenon "rarely focus on student engagement from a philosophical perspective, and consequently the term has become a popular, but at times, an empty and superficial, catch-phrase or slogan" (p. 60). They identify three foundational conceptualizations of student engagement from which current conceptions of student engagement stem: *traditional* (or conservative), *liberal* (or progressivist), and *critical-democratic*. These perspectives are named partially in reference to the work of Dewey (1938) who made the distinction between "traditional" education and "progressivist" education.

The traditional model (also referred to as a *transmission* model of teaching) describes an approach to education that is fundamentally teacher-centred, in which the teacher, as an authority figure, holds full control of the classroom and curriculum, and is responsible for "transmitting" information to students who sit passively in order to receive the material. A definition of student engagement that emerged out of this approach viewed student engagement as a set of characteristics thought to be present in a so called "engaged student" (e.g., Finn & Zimmer, 2012; Steinberg, 1996; Strong, Silver, & Robinson, 1995) (i.e., a student who attends class, pays attention, completes homework, and excels in curricular and extracurricular endeavors). Working within the traditional model, Bianchi and Munro (2008), for instance, define student engagement as "the level of involvement in and commitment to all aspects of the process of learning academic knowledge" (p. 92), and as a determinant of student achievement. Fredricks, Blumenfeld, and Paris (2004) state that the term "in both popular and research definitions, encapsulates the qualities that are seen as lacking in many of today's students" (p. 60). McMahon and Portelli (2004) suggest that certain scholars who adopt the traditional view of student engagement see engagement as good, and lack of engagement as bad, blaming the students for being unengaged, and at times suggesting a punitive approach to address the problem (p. 64). Finn and Zimmer (2012), for example, consider successful students (who attend class, pay attention, and are non-disruptive) as being engaged, and students who exhibit antisocial, inattentive, and/or disruptive behaviour as being unengaged.

Theories which reflect Dewey's (1938) "progressivist" model, are more student-centred and see teaching and learning as social processes. This differs significantly from the traditional model which views curriculum as a product that must be imposed on the student by the instructor. Dewey suggests that within the progressivist model, students should take an active role in the process of learning, and that curriculum should be grounded in their own experiences and realties. Further, the learning process is seen as occurring through interactions with instructors, peers, and the community. This conceptualization of student engagement is what McMahon and Portelli (2004) define as the liberal perspective. This view acknowledges the multiple players involved in creating and fostering engagement; it recognizes that factors involved in student engagement extend beyond internal qualities within a student that must be maintained by the instructor. Where the traditional perspective sees student engagement through the lens of a deficit model, the liberal perspective acknowledges that engagement does not exist in the student psyche alone. The engagement phenomenon, therefore, involves the students, instructors, and classroom environment, as well as the school administration, and a broader community (e.g., Dotterer & Lowe, 2011; Gasiewski et al., 2012).

McMahon and Portelli (2004) suggest that the liberal definition of student engagement still falls short, however, because although the liberal model is not a deficit model, and does strive to include student voices and autonomy, it still conceptualizes student engagement as something that instructors can do *to* students. The assumption of the liberal conceptualization is that if instructors employ certain strategies or exhibit certain characteristics, students will be engaged. McMahon and Portelli instead suggest a critical-democratic approach to teaching and learning based on the work of Dewey (1938), Freire (1998), and hooks[11] (1994). This approach, referred to most commonly as "engaged pedagogy" (hooks, 1994), challenges the tendency to measure success in terms of the qualities valued by the dominant society and status quo. This holistic approach stresses the need to constantly question the worthwhileness of curricula and the purpose of student engagement, and to think critically about power in society while always grounding concepts in students' lived realities. McMahon and Portelli (2004) define the critical-democratic conceptualization of student engagement as a multifaceted phenomenon where engagement is seen neither as inherent in successful students nor as something instructors are required to do to students, but rather a phenomenon which "organically manifests within and between students and teachers within the temporal and spatial context" (Chavez & O'Donnell, 1998, p. 2). McMahon and Portelli (2004) state:

[11] Scholar and social activist bell hooks (née Gloria Jean Watkins) uses unconventional lowercasing of her name as a personal, professional, and political statement.

> As a multifaceted phenomenon, engagement is present in the iterations that emerge as a result of the dialectical processes between teachers and students and the differing patterns that evolve out of transformational actions and interactions. As enacted, engagement is generated through the interactions of students and teachers, in a shared space, for the purpose of democratic reconstruction, through which personal transformation takes place. (p. 70)

Although the implementation of this kind of pedagogy may not be practical or even relevant within all teaching situations, the critical-democratic approach to pedagogy (Freire, 1998; hooks, 1994) makes an important contribution to education research. The work of McMahon and Portelli (2004) highlights the fact that the majority of the current research on student engagement offers prescriptive or stipulative definitions, many of which seem to echo a traditional perspective in which engagement is identified by a combination of external behaviours resulting in academic achievement. However, as discussed in the next section, some scholars do treat student engagement differently, as developing through interaction in the classroom. The next section delves into the discussion of the two schools of thought that inform current definitions of student engagement.

3.2 Current Definitions of Student Engagement: Achievement or Interaction?

As mentioned at the beginning of this chapter, current research on the phenomenon of student engagement appears to draw from two schools of thought: the academic achievement approach and the interactive approach. The academic achievement approach views student engagement as synonymous with academic achievement and success, or, alternatively, as a kind of ‘secret ingredient’--cloaked in a variety of testable factors--which, when possessed by students or implemented by institutions, amounts to academic success. The interaction approach views student engagement as a state of being, generated by involvement in classroom activities, and through interaction between students, instructors, and peers.

3.2.1 Academic achievement approach

Predominantly, current literature on student engagement (e.g., Chi & Wylie, 2014; Chi et al., 2018; Dotterer & Lowe, 2011; Klem & Connell, 2004; Strong et al., 1995; Zepke & Leach, 2010) subscribes to the academic achievement approach which tends to view the phenomenon as taking three forms: *behavioural engagement*, *emotional engagement*, and *cognitive engagement* (Chi & Wylie, 2014; Chi et al., 2018; Fredricks et al., 2004;). These forms of engagement refer to the ways that students think, feel, and behave in relation to academic achievement. Behavioural engagement involves participation and positive conduct in the school and classroom (e.g., completing homework, attending class), involvement in academic and social extracurricular activities (e.g., participation in sports and school governance), and behaviours such as effort, persistence, attention, and participation in class. Emotional engagement includes students’ affective reactions to teachers, peers, and academics and involves students’ feelings of boredom, anxiety, and (dis)interest. Cognitive engagement refers to investment in academics, and encompasses students’ willingness to learn, exert effort, and persevere when faced with challenges. Fredricks and colleagues (2004) note that, from study to study, these definitions often vary, overlap, and at times resemble theories of motivation as opposed to theories of student engagement.

Some scholars of the academic achievement approach tend to use student engagement as a stand-in, or a synonym, for learning outcomes such as student success and satisfaction (e.g., Skinner & Belmont, 1993; Zhao & Kuh, 2004), whereas others omit a definition altogether (e.g., Carini, Kuh, & Klein, 2006; Umbach & Wawrzynski, 2005). In these cases, scholars tend to adopt the use of questionnaires or surveys such as the Student Course Engagement Questionnaire (SCEQ) (Handelsman, Briggs, Sullivan, & Towler, 2005), or most commonly, the National Survey of Student Engagement (NSSE) (e.g., Carini et al., 2006; Zhao & Kuh, 2004). The NSSE uses student surveys to assess aspects of the student experience at participating universities (currently across Canada, the United States, and six other countries worldwide) (NSSE Institute, 2019). The NSSE defines student engagement as referring to the amount of time and effort students put into their studies and other educationally purposeful activities as well as how institutions deploy resources and organize curriculum in order to involve students in activities linked to learning and development (NSSE Institute, 2019). Some scholars, Solomonides (2013) for instance, challenge the wide-spread use of surveys such as the NSSE, for conflating the notion of student engagement with that of the student experience, a notion shaped by neoliberalist thinking about the marketization of higher education which positions students as consumers (p. 49).

While there remains little agreement on the precise definition of student engagement, there are consistent commonalities across research which subscribes to the academic achievement approach. Namely, the belief that engagement is a phenomenon involving a variety of factors, both internal (behavioural, emotional, cognitive) and external (extracurricular activities, academic resources, curriculum), and that it is intrinsically linked to students' academic success. It must be stressed that this body of research is not without some merit. Indeed, it makes good sense that factors such as motivation, persistence, attention skills, support services, and quality curriculum may result in academic achievement. It does seem necessary to acknowledge though, that this view of student engagement differs considerably from that of the interactive approach.

3.2.2 Interactive approach

Although McMahon and Portelli (2004) maintain that the majority of current definitions are based in the traditional perspective, there is also quite a number of definitions that are decidedly student-centred, and which focus on the inclusivity of student voices and autonomy (e.g., Gasiewski et al., 2012; Ratcliffe & Dimmock, 2013). This is a trend, which Dunne and Owen (2013) suggest is becoming increasingly common. Some studies even go beyond student-centred approaches and towards more of a critical-democratic conceptualization by having students participate in the co-construction of their curriculum (e.g., Bovill, 2013; Cook-Sather, Bovill, & Felten, 2014; Walton, 2013), while others, although admittedly few, provide definitions of student engagement which reflect the importance of interpersonal relationships and interaction in the realization of engagement (e.g., Biza, Jaworski, & Hemmi, 2014; Pianta, Hamre, & Allen, 2012). It is this body of research that forms the interactive approach to student engagement. For example, Pianta and colleagues (2012) conceptualize student engagement in elementary school contexts "not as a property of a child but rather as embedded in interactions and relationships" (p. 367) and make reference to engagement in certain activities as involving focused energy, enjoyment, and a state of "flow" (p. 369) defined as a mental state of total immersion in an activity wherein the actor is fully involved in performing the task without conscious thought of anything beyond the task and is only focused on the task itself (see Csikszentmihalyi, Abuhamdeh, & Nakamura, 2005) [12]. Gettinger and Walter (2012) focus specifically on "academically engaged time" in which student engagement is conceptualized as direct, measurable involvement or participation in learning activities, while Biza, Jaworski, and Hemmi (2014) base their position on the work of Vygotsky (1978) which proposes that cognition develops through participation in sociocultural contexts; that is, they see engaged learning at the university level as taking place through "interactions in social settings, specifically within the communities in which university students, their teachers, research students and researchers interact" (p. 162). Finally, Zepke and Leach (2010), though clearly situated in the academic achievement approach, mention briefly in passing that there exists a form of engagement, which they refer to as "transactional engagement," that occurs when students and teachers interact with each other (p. 169).

These definitions encapsulate the *in situ* nature of student engagement as it occurs within, and as a result of, in-class interactions. Further, the interactive approach captures student engagement as impermanent or "ephemeral" and requiring the focused/rapt attention of interested parties. When this type of engagement is realized, moments of excitement, intense interest and concentration, or "flow" (Csikszentmihalyi et al., 2005) can occur. Although student engagement described by the interactive approach is

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[12] In a recent critical narrative review of literature of engagement, Padgett et al., (2018) discuss the relationship between flow and engagement. They observe that while some researchers equate flow and engagement as essentially the same phenomenon, ultimately the two are distinct (pp. 3-4).

different than that described by the academic achievement approach, there is a degree of similarity between them. First, student engagement as described by the two approaches is conceptualized as multifaceted and difficult to measure (it could be argued, though, that because of the impermanent and in situ nature of student engagement as defined by the interactive approach, its measurement could be that much more challenging). Second, both approaches to student engagement acknowledge that internal factors such as attention and enjoyment of the curriculum play some role in the phenomenon. Finally, both view interaction with instructors as important, although the academic achievement approach sees interaction as one of many "ingredients" in the "recipe" for achievement, and the interactive approach sees interaction as a medium for the generation of student engagement.

3.2.3 New developments in engagement research

Increasingly, proponents of the academic achievement approach are aligning themselves more closely with the idea of engagement as an inherently interactive phenomenon. For instance, a group of scholars (Fredricks et al., 2016; Wang et al., 2016), from the academic achievement camp, have added an additional dimension of *social engagement* to their popular three-pronged--based on behavioural, emotional, and cognitive dimensions--understanding of engagement. The social dimension refers to the quality of social interactions with peers and adults, and the willingness to invest in creating and maintaining those relationships while learning (Wang et al., 2016, p. 17). The work of Chi and colleagues (e.g., Chi & Wylie, 2014; Chi et al., 2018), which is also based in the academic achievement approach, focuses on measuring students' cognitive engagement while they learn, specifically, the extent to which students engage with learning materials in the classroom context as reflected in the overt behaviours they exhibit while undertaking a learning activity or task (Chi & Wylie, 2014, p. 219). Particularly relevant here is the authors' view that learning activities and their resulting overt engagement behaviours can be differentiated into one of four hierarchical modes: (1) Interactive, (2) Constructive, (3) Active, or (4) Passive, together forming the ICAP framework (p. 221). Importantly, the second, constructive level of learning, stems from Vygotskian notions of instructional "scaffolding" (Wood, Bruner, & Ross, 1976, p. 90), wherein learners generate knowledge collaboratively with more capable peers or instructors. As well, Chi and Wylie (2014) describe the highest level of learning, that is, interactive learning, as occurring through mutual exchanges of ideas between two or more individuals (i.e., "dialoguing") resulting in the formulation of new ideas or generating new-found knowledge (p. 223).

While useful, one potential shortcoming of the ICAP framework and the majority of research on student engagement reviewed thus far is the understanding of student engagement as a one-size-fits-all concept. To date, there has been only some recognition that the factors which influence student engagement in educational contexts change as students progress through elementary, secondary and post-secondary education (e.g., Scanlon, Rowling, & Weber, 2007). In their recent critical narrative review of literature focusing on engagement in educational and workplace contexts, Padgett at al., (2018) identify a few studies that have begun to view engagement as context-*dependent* or context sensitive (e.g., Fulmer et al., 2015; Shernoff, et al., 2016). That is, they see the levels of student engagement (including behavioural, emotional, and cognitive dimensions) as significantly affected by the quality of the learning environment; thus, they view the *degree* of engagement as dependent on the environment, specifically, on the "environmental complexity" consisting of the simultaneous presence of environmental challenge and support (Shernoff, et al., 2016, pp. 52-53). This perspective views engagement as a product of the learner and the learning context and the interaction of the learner with the context. Further, is has been proposed that different models and measures be developed and used for assessing multiple factors influencing levels of student engagement in different contexts (Fulmer, D'Mello, Strain, & Graesser, 2015; Padgett et al., 2018; Shernoff, et al., 2016). One such measure is the mathematics and science engagement survey (Wang et al., 2016; Fredricks et al., 2016) developed for measuring student engagement and predictors of academic achievement in mathematics and science classrooms in elementary and secondary school contexts. Wang and colleagues make the point that simply adapting general engagement measures for use in specific classes is a limited approach "because it does not take into account domain specific aspects of engagement and assumes engagement is manifested similarly across different subject areas" (Wang et al., 2016, p. 24; see also Fredricks et al., 2016). The authors' research underscores the need for developing assessments specifically designed to assess student engagement in the mathematics and science domains. By suggesting that some indicators of engagement may be unique to or reflected differently in specific domains, the study conducted by Wang et al., (see also Fredricks et al., 2016) emerges as one of very few, which acknowledge that student engagement *itself* may be realized differently in different contexts. I would argue, however, that defining mathematics and science across elementary and secondary school classrooms as one domain is still an overly broad net to cast (for example, based on this model, student engagement in 6th

grade science classes is evaluated on the same scale as student engagement in the 12th grade mathematics classrooms). If engagement is indeed generated through interaction, be it face-to-face student-instructor interaction (e.g., Pianta et al., 2012), interaction between the learner and learning environment (e.g., Shernoff, et al., 2016), or ultimately through discourse or "dialoguing" with instructors and/or peers (e.g., Chi et al., 2018), the need for a *domain*- and *context-specific* understanding of student engagement appears more reasonable for any approach that views meaning-making as a socially situated rhetorical action (e.g., Bakhtin, 1986; Miller; 1984, 2015; Räisänen, 2015; Rogoff, 1990; Swales, 1990) (see Chapter 2, Section 2.5). One scholar who has acknowledged such specificity in his research on engagement in written genres is Hyland (2001, 2005), whose work is discussed in the next section.

3.3 Engagement in Written Genres

Like a number of other scholars described in the previous section (e.g., Pianta et al., 2012; Zepke & Leach, 2010), Hyland (2001, 2005) defines engagement in terms of interaction; specifically, he describes the ways in which the writers of scholarly publications engage with their audiences (i.e., the readers). This definition is a suitable starting point for my investigation of student engagement in mathematics lectures from the perspective of teachers, as Hyland's definition originates with the writer's perspective. Hyland's (2005) theory of *textual engagement* points out that "meanings are ultimately produced in the interaction between writers and readers in specific social circumstances" (p. 175). Importantly, by recognizing that "all language use is related to specific social, cultural and institutional contexts," Hyland acknowledges the social situatedness of meaning-making and observes that the rhetorical strategies used by writers to engage their readers are shaped by the "discoursal preferences" of the disciplinary communities to which they belong (pp. 173-174; cf. Swales, 1990). Hyland (2005) defines engagement as a form of interactional alignment between participants (in this case, writers and readers) in an unfolding dialogue, or, more specifically, "an alignment dimension where writers acknowledge and connect to others, recognizing the presence of their readers, pulling them along with their argument, focusing their attention, acknowledging their uncertainties, including them as discourse participants, and guiding them to interpretations" (p. 176). The strategies writers have been shown to use in order to engage their readers include the use of reader pronouns, directives, reference to shared knowledge, personal asides, and in particular, posing questions, which Hyland describes as "the strategy of dialogic involvement *par excellence*, inviting engagement and bringing the interlocutor into an arena where they can be led to the writer's viewpoint" (p. 185; emphasis in original). However, by drawing on a corpus of publications from journals across eight disciplines, the 2005 study presents only a very broad representation of the phenomenon of engagement in written genres; more fine-grained investigations, Hyland suggests, would no doubt offer further insights into disciplinary-specific discursive patterns and behaviours. Several scholars have taken up Hyland's call for research into disciplinary-specific discursive patterns and behaviours in written texts, of particular relevance is the work of McGrath and Kuteeva (2012) whose analysis of stance and engagement in pure mathematics research articles confirmed that Hyland's (2005) framework can be usefully applied to mathematics (written) academic discourse (p. 161).

As mentioned (Chapter 1; Chapter 2, Section 2.2.1), chalk talk is a way of teaching university mathematics that developed within the global discourse community of mathematics professors (Artemeva & Fox, 2011; see also McGrath & Kuteeva, 2012) as a situated disciplinary practice (Artemeva & Fox, 2011; Fox & Artemeva, 2012). Discourse of teaching mathematics is multimodal in that it joins together a number of communicative modes including writing, speech, gesture, movement, and mathematical symbolism (cf. O'Halloran, 2005), thus, a study of university mathematics teaching is a study of multimodal embodied discourse (cf. Sfard, 2014), and, as such, chalk talk can be seen a highly complex discursive pedagogical practice (Fogarty-Bourget, 2013; Fogarty-Bourget, Artemeva, & Fox, 2019; Fox & Artemeva, 2012; O'Halloran, 2005). Consequently, in my investigation of strategies used by university mathematics instructors to help facilitate student engagement in chalk talk lectures, I invoke Hyland's notion of engagement in written discourse as a starting point. Further, by drawing on my interactions with members of the university mathematics community, both students and instructors, discussed in Chapter 5, I develop an understanding of student engagement that is reflective of the disciplinary context in which it occurs.

I begin the discussion by defining engagement as a state of interactional alignment between the instructor and students in the unfolding dialogue of the chalk talk lecture. The instructor uses various discursive behaviours and strategies to "acknowledge and connect to" students, by "recognizing" their "presence . . ., pulling them along with their argument, focusing their attention, acknowledging their uncertainties, including them as discourse participants, and guiding them to interpretations" (Hyland, 2005, p. 176), and, in doing so, helps to realize student engagement in the classroom. In line with

Hyland's definitions, I refer to these discursive behaviours and strategies as "engagement devices" (p. 188).

As scholars from different fields have acknowledged, humans draw on a variety of meaning-making means that "almost *always appear together*: image with writing, speech with gesture, math symbolism with writing and so forth" (Jewitt, Bezemer, & O'Halloran, 2016, p. 2; emphasis in the original). In other words, engagement needs to be understood as a multimodal phenomenon and studied as such (cf. Fogarty-Bourget, Artemeva, & Fox, 2019, p. 277). Following this observation, I depart from Hyland by viewing all discourse as multimodal (see also Kress & van Leeuwen, 1996/2006; Norris, 2004; Räisänen, 2015) and thus, see a study of discourse as a study of *multimodal* meaning-making. In doing so, I align myself more closely with multimodal researchers such as Bernad-Mechó and Fortanet-Gómez (2019) who draw on Hyland's (2005) concept of "engagement markers" and apply it to the multimodal investigation of different styles of open-access online social-science lectures (see also Bernad-Mechó, 2017; Bernad-Mechó & Fortanet-Gómez, 2017).

In the next chapter, I review previous empirical research on student engagement in educational contexts. After introducing the existing body of literature on student engagement in elementary and secondary school contexts, I narrow down my review to focus on student engagement in post-secondary education, STEM lecturing, and, specifically, university mathematics teaching.

Chapter 4: Literature Review

As discussed in the previous chapter, many different facets of student engagement have been identified over the last 30 years (e.g., Astin, 1984; Chi et al., 2018; hooks, 1994; Kuh et al., 1991; Pace, 1984). As numerous large-scale reviews have demonstrated (e.g., Fredricks et al., 2004; Padgett, et al., 2018), there exists a growing body of empirical research dedicated to the identification and description of the phenomenon of engagement and the many factors involved in facilitating student engagement in educational contexts. Not all authors explicitly refer to the phenomenon of engagement (e.g., Scanlon et al., 2007; Wubbels & Brekelmans, 2005), but their research nonetheless provides insights into this complex concept. What is also important to note, is that there is significant variation in the terminology used across these studies, not just in defining engagement, but also in reference to the antecedents, principles, and constructs that form the intricate web of factors thought to relate to an already complex phenomenon. Among these, the term "classroom context" is most frequently used as an overarching term that encompasses countless influential factors or is used interchangeably with the terms "learning environment," and "classroom climate". It is worth noting that Fredricks, Blumenfeld, and Paris (2004), for instance, include in "classroom context" such factors as teacher support, classroom structure (i.e., students' adherence to instructors' expectations for academic and social behaviour), classroom climate, and educational task characteristics[13]. Fredricks, Blumenfeld, and Paris (2004) also identify the factor of

[13] In the years since their large-scale review was published, the complex concepts of the "learning environment" (e.g., Wang et al., 2016) and "educational task" (e.g., Fulmer et al., 2015) have been further problematized and developed.

"individual needs," including students' needs for relatedness, autonomy, and competency, which acts as a mediator between classroom context and engagement.

In this dissertation, I differentiate between the learning environment (which includes factors such as class size, teaching mediums and technologies, classroom structure, and teaching style) and classroom climate (influenced by student-instructor interactions and relationship quality) and consider both under the umbrella term of "classroom context"[14]. I consider the degree to which students' individual needs are acknowledged and/or met within a particular learning environment as an aspect of classroom context.

Empirical research on student engagement is extensive, and much is not applicable to university mathematics education contexts. An exhaustive review of such research literature is beyond the scope of this dissertation nor would it fit the purpose of this dissertation. In the following sections, I review publications that contribute to the development of the definition of student engagement in chalk talk specifically by focusing on studies which identify and discuss aspects of the classroom context and types of instructors' multimodal behaviours that relate to the teaching and learning of university mathematics. I begin by reviewing influential studies of student engagement in elementary and secondary school settings, followed by research focusing on the student experience in post-secondary education (including the school-to-university transition) and undergraduate student engagement in STEM. The final subsection reviews previous research on university mathematics teaching with a focus on chalk talk lecturing.

[14] For reasons of clarity, I try to avoid such overarching terms and refer to specific individual factors whenever possible.

4.1 Student Engagement in K-12 Classrooms

The majority of student engagement research literature focuses on teaching and learning in elementary and secondary school contexts from levels kindergarten to grade 12 (K-12). While research on student engagement in elementary school contexts may not be directly related to student engagement in chalk talk lectures, such studies as Finn and Zimmer (2012), for instance, present substantial empirical support suggesting that post-secondary outcomes are affected by students' engagement in elementary and secondary school. As well, this body of research informs our understanding of the student engagement phenomenon more generally (e.g., by describing factors shown to contribute to student engagement such as student-instructor interaction, and identifying possible impacts of student engagement in K-12 on their participation in post-secondary education [e.g., Finn, 2006]). As well, research focusing on upper-year secondary school contexts (grades 11-12, for example) may be particularly useful for understanding student engagement in introductory university courses since many students move directly from grade 12 into post-secondary education. I begin by discussing research on K-12 classroom contexts and further narrow down to studies of student and instructor behaviour in the K-12 classroom.

Dotterer and Lowe (2011) in a study of student engagement in elementary school contexts found that the classroom context is an important predictor of student engagement, particularly for academically at-risk students. The researchers collected quantitative data from classroom observations, self-reports, and standardized assessments of 10,14 students in 5th grade. The results showed that classroom climates that are enhanced by positive student-instructor relationships and high teacher sensitivity and receptivity create more enjoyable learning environments for students and thus contribute to students' desire to pay attention and engage in learning. Their findings support the assertion that enhancing classroom contexts with high quality instruction, a positive atmosphere, and reduced student–teacher conflict can increase student engagement which, in turn, enhances academic achievement (p. 1657). A study by Wang and colleagues (2016) focused more specifically on mathematics and science classroom contexts. They conducted a sequential mixed-methods study of student engagement in these contexts by gathering quantitative data from 3883 middle school and high school students' responses to the math and science engagement survey and qualitative data from open-ended interviews with 65 mathematics and science teachers. Their analyses revealed elementary and secondary mathematics and science classrooms to be complex social systems and shared learning environments in which teachers and students become jointly focused on accomplishing academic activities. Further, the researchers identify student engagement as a social mechanism influential to the quality of classroom interactions and thus students' achievement in mathematics and science. The findings of their study support both a multidimensional (academic achievement) perspective as well as a more general (global) understanding of student engagement which they suggest can be applied to investigating students' motivation in pursuing STEM careers (p. 24). Shernoff and others (2016) also examined the relationship between classroom context and student engagement by investigating the secondary school learning environment described as a primary mechanism of control by which teachers can facilitate student engagement in the classroom (p. 52). The researchers collected data from classroom observations (in person and video-recorded) and in-class surveys of students' moment-to-moment classroom experience. Their results showed that environmental challenge, whereby students are comfortably challenged in the classroom and supplied with clear goals that guide student action, and environmental support including social and emotional instructional support and scaffolding (cf. Rogoff, 1990; Vygotsky, 1987, Wood, Bruner, & Ross, 1976), have a significant effect on student engagement. These findings highlight the extent to which environmental and behavioural factors overlap to influence student engagement within the classroom.

To investigate teachers and students understanding of student engagement and disengagement in mathematics and science classrooms, a group of researchers (Fredricks et al., 2016) conducted a study using qualitative methods. The researchers collected data from semi-structured interviews and focus groups with 106 elementary and secondary students and 34 of the students' mathematics and science teachers. The researchers identified specific behaviours that the student and teacher participants reported as demonstrative of student engagement in learning. These behaviours include showing interest, paying attention, and participating in classroom activities such as class discussions, namely by sharing and expanding on ideas (p. 12). Fredricks and colleagues also identified behaviours that were indicative of "math and science disengagement". These behaviours included demonstrating low-effort and shallow involvement in problem-solving activities, dozing off, playing on phones, appearing bored, doing only the minimum work required, and talking with friends (p. 13).

Focusing on the relationship between teacher behaviour and student engagement, Skinner and Belmont (1993) conducted a year-long quantitative study to investigate time as a potential variable for influencing student engagement in elementary school classrooms. Using survey and interview data collected from 144 elementary school students and their 14 teachers, the researchers found strong empirical support to suggest a reciprocal relationship between teachers' behaviour towards the students and students' active engagement in the classroom. Their results indicated that when students perceive their instructors as warm and supportive, they experience a more positive affect in the classroom and are more engaged as a result. When teachers are less involved with students, however, students perceive them as less consistent and more coercive (p. 577). Based on their findings, Skinner and Belmont concluded that student-instructor interactions can be a strong predictor of student engagement, with one-on-one classroom interactions having the most powerful impact on students' levels of engagement in the classroom.

Similar conclusions were drawn by Wubbels and Brekelmans (2005) who reported on the results of a 25-year program of research aimed at investigating the relationship between student achievement outcomes and teacher behaviours. Their research team developed a survey instrument used to catalogue students' and instructors' reported perceptions of instructor behaviours and teacher–student relationships, and measure student achievement outcomes. Using the survey instrument, they collected quantitative data from students and teachers in high school classrooms across more than 10 countries. The results of the research showed a connection between teacher-student relationships in the classroom and student achievement outcomes. Wubbels and Brekelmans (2005) reported on multiple studies that showed instructors who demonstrated high levels of "influence" (conveyed through such behaviours as dominance, leadership, organization, and attentiveness) and "proximity" (conveyed through such behaviours as cooperativeness, interest, supportiveness, friendliness) toward students were associated with high student achievement outcomes. They also suggest that nonverbal behaviour is particularly important for influencing how students perceive these qualities. Wubbels and Brekelmans explain that variations in the way that new and experienced teachers use nonverbal behaviour while teaching may help explain the difficulties that some new teachers have in creating positive relationships with students (pp. 15-16). Results of their report indicate that “on stage” teaching (i.e. when teachers stand in front of the whole class and lecture) seems to be more important than individual or small-group teaching for establishing a teacher identity and, consequently, shaping students’ behaviour during “seatwork” (p. 16). For example, teachers with disorderly classrooms, who were rated as being uncertain and lenient, or uncertain and aggressive/drudging reflected relatively low student achievement outcomes whereas teachers rated as authoritative, directive, and tolerant showed relatively high outcomes. The more teachers were perceived as cooperative, the higher was students’ level of achievement. Wubbels and Brekelmans’ research also investigated teachers’ use of classroom space, body positioning, facial expressions, gaze, and voice. Their findings showed that the longer teachers spoke using a lecturing volume, the more they were perceived by students as dominant, whereas the longer they spoke quietly, the more they were perceived as being submissive. Teachers who stood relatively far from students, with the head help upright, scanning the classroom, and talking for longer periods in a relatively deep voice were rated as having a high level of influence. Teachers who stood close to students, and who kept their head down so that their faces were less visible, and used less eye contact were rated as having low influence. Interestingly, these findings showed that the features perceived as dominant and with a high influence were demonstrated by experienced teachers almost twice as much as by new teachers (i.e., novices). In light of these results, Wubbels and Brekelmans suggested that it might be helpful for novice teachers to portray the image of an experienced teacher whenever they address the class in order to facilitate positive student relationships and enhance student engagement. However, the researchers warn their readers that in these cases whole-class teaching should be limited to shorter periods in order to lessen the risk of "breaking character" (p. 18). The influence of instructors' behaviours and attitudes on student engagement is not limited to elementary and secondary school contexts. Research on student engagement in post-secondary contexts suggest that student-instructor relationships and interactions, in coordination with aspects of the learning environment, shape students' active engagement in learning (e.g., Gasiewski et al., 2012; Scanlon et al., 2007). The following section discusses the unique learning contexts of higher education, with a focus on large-lecture classrooms and teaching.

4.2 Post-secondary Transitions: Adjusting to the Undergraduate Experience

As students progress through their education from elementary to secondary and eventually post-secondary schooling, they experience a number of transitions. The transition to first-year university from high school requires that students adjust to new and unfamiliar teachers, peer groups, learning contexts, and pedagogical approaches (Allen et al., 2011). Inevitably, many of the factors that may influence students' engagement in classroom contexts also change. For example, the majority of students in higher education have made their own choice to continue their schooling, so enhancing student motivation may not be as necessary as in secondary school contexts. Furthermore, in many cases, having the ability to select an area of study means the curriculum being taught (ideally) holds more obvious relevance to students' lives and interests than it may have in previous schooling. Students in college and university may, nonetheless, struggle with the first-time transition to post-secondary educational contexts, many of which come with new sets of rules and expectations (e.g., Scanlon et al., 2007) that are quite often disciplinary-specific (e.g., Artemeva, Logie, & St-Martin, 1999; Gasiewski et al., 2012). To investigate the student experience through the first-year transition to university, Scanlon, Rowling, and Weber (2007) conducted a mixed-methods study using survey data collected from 602 first-year students across six different faculties at two universities and qualitative data from semi-structured follow-up interviews with 27 self-selected student volunteers from the larger sample. Scanlon and colleagues found that, in the transition from high school to university education, students experience a sense of loss for familiar learning contexts and communities (p. 238). Namely, students in their study reported difficulties adjusting to new and unfamiliar interactions with lecturers who appeared inaccessible to the students, in part because first-year students' "ideal" instructors are often modelled after those they have encountered in secondary school (p. 232). Similar findings were presented by Bryson and Hand (2007) who conducted a qualitative study using data from focus groups with 50 students enrolled in a university business school to investigate engagement from the undergraduate student perspective. They found that first-year university enrollments reported particularly low levels of engagement in part due to difficulties associated with the transition to university from high school or college contexts. Overall, this research showed that instructors' skills as professional communicators were influential to levels of student engagement in the classroom, and particularly important was the level of enthusiasm instructors conveyed towards teaching and the subject matter. In line with research on student engagement in some K-12 learning contexts (e.g., Skinner & Belmont, 1993; Wubbels & Brekelmans, 2005), Bryson and Hand concluded that, frequently, opportunities for enhanced engagement seemed to stem from the behaviour or approaches taken by the instructors (p. 357). Student participants in their study reported being more engaged when learning from instructors who generated a sense of warmth, sharing, and respect in the classroom, provided opportunities for students to participate in lectures, and created a climate where a sense of belonging and mutuality could flourish (p. 360).

Establishing a learning environment in which students feel welcomed, acknowledged, and supported may be more difficult for instructors teaching large, introductory classes in sizable lecture halls (Cretchley, 2005). Student participants in Scanlon, Rowling, and Weber's (2007) study reported feelings of anonymity resulting from large-lecture style courses. Scanlon and colleagues observed that first-year students were generally "unprepared for the size of lectures" and the way that the size of lecture halls defined interactions with lecturers (p. 233). Students in the study further commented that they felt large class sizes meant there was "no personal connection with instructors" whom they saw as distant and remote, as "people who stood there and talk[ed] at them" (p. 233). The student participants reported feeling an interpersonal distance between themselves and their instructors due to lack of communication and face-to-face interaction, as well as physical distance resulting from student-instructor interactions that were limited to email or consultation-by-appointment. Classroom contexts such as these are unique to higher education, and large-lecture style courses in particular are the traditional means of teaching introductory STEM courses (Gasiewski et al., 2012), including chalk talk lectures. Research on student engagement in post-secondary STEM disciplines is discussed in the next section.

4.3 Instruction in Introductory STEM Courses

For some, introductory STEM courses are seen as a potential barrier to students' professional aspirations in STEM disciplines (e.g., pursuing specializations in medicine), in part, because students' overall achievement in STEM majors has been linked to their engagement in those courses (Gasiewski et al., 2012). To investigate student engagement in introductory STEM lectures, Gasiewski and colleagues (2012) conducted a large-scale mixed-methods study using sequential exploratory design procedures. They surveyed 2,873 students in 73 introductory STEM courses across 15 institutions, as well as the faculty teaching the courses. The researchers also conducted follow-up focus group sessions with 241 students from 8 of the participating institutions. Their results showed that, overall, the students in their study were not particularly enthusiastic about large-lecture style teaching and preferred instead when instructors used innovative pedagogical techniques involving short videos, small-group work sessions, and online quizzes. Specifically, the quantitative results showed that students who described a particular course as predominantly lecture-based tended to report significantly lower levels of engagement in the course. This finding was supported by qualitative data from follow-up interviews in which students reported often feeling unengaged and unenthusiastic in these contexts (p. 246). And yet, among the participants of the study, there was a group of students, primarily pre-med, who indicated that they preferred STEM courses to be offered in traditional lecture-style format because they found it best for covering the vast amount of material required for success in upper-level courses.

Some scholars (e.g., Bullock et al., 2002; Maclaren, Wilson, & Klymchuk, 2018) believe that implementing teaching technologies such as wireless student response systems (also referred to as “clickers”), and web-based tools such as online tutorials, quizzes, and discussion forums, is one way to mitigate the risks associated with large class sizes while limiting the costs associated with higher ratios of instructors to students. The use of such teaching technology has been described as “a vehicle for mandatory, personalized student engagement” capable of creating “a better learning environment in a large-lecture setting while simultaneously reducing operating costs” (Bullock et al., 2002, p. 31). To test the potential benefits of these teaching technologies, namely clickers, Bullock and colleagues conducted a study of “approximately the same” 200 undergraduate students in an algebra-based physics course over two semesters (p. 31). The first “control” semester covered Newtonian mechanics and did not use teaching technology, whereas the second semester covered electricity and magnetism, and implemented the clickers as well as an additional online quiz component. The results showed overwhelming improvement in attendance, participation, and exam scores which the researchers interpreted as increased engagement. Although the authors do not describe any limitations of their study, several problems are evident. First, participation was measured in the second semester by student responses using the clickers, and students were graded on their responses. It is not clear how student participation was measured in the first semester when no clickers were used; students may have been engaging in discussion, asking questions, or participating nonverbally (e.g., eye contact, nodding). Further, no grades were allotted to students for traditional participation in the first semester and thus, there was no additional incentive to participate. Second, the improvement noticed in attendance, participation, and exam results may have been impacted by the fact that the subject matter had changed, and that students were into their second semester by the time the technology was being tested. They had already completed and received feedback on the exams from the previous semester, and weaker students may have dropped out, thus affecting the overall results. Finally, although implementation of the teaching technology was promoted as highly cost effective, the savings seemed to accrue from eliminating TA positions, and by offloading the cost of the clickers onto the students. It is unclear how such procedures may affect student engagement, nor is it yet understood how learning and engagement resulting from such teaching technologies compare to traditional approaches. Gasiewski and others (2012) note that, unfortunately, the research regarding the effectiveness of teaching technologies is somewhat limited, often involving small sample sizes, and researcher bias (p. 233). As part of their large-scale study, Gasiewski and colleagues tested the use of clickers in large-lecture classrooms and found that teaching technologies *can* enhance student engagement by increasing participation and feedback, however, in classrooms that could not afford the teaching technology equipment, student responses were gathered using paper and pens and the results were similar. This suggests that it may not be the teaching technologies themselves, but the use of teaching strategies which encourage student engagement by incorporating collaborative activities into large-lecture classrooms (Gasiewski et al., 2012, p. 232).

As numerous scholars point out, calls for incorporating active-learning strategies into traditional undergraduate STEM lectures are mounting and becoming increasingly strident (e.g., Auerbach et al., 2018; Wood et al., 2017). However, there is some empirical support to suggest that the effectiveness of active-learning strategies and the degree to which they are context-appropriate depend on a variety of factors. As part of a recent comparative study of novice versus expert instructors, Auerbach and colleagues (2018) investigated the relationship between the successful implementation of active-learning approaches in undergraduate science courses and "teacher knowledge" (i.e., the knowledge about teaching that instructors possess and develop through iterative experience and reflection) (p. 3). The study showed that the potential positive impact of such approaches on student learning and retention may depend on the teaching experience of the instructor and their accruement of teacher knowledge. The authors conclude that more research needs to be done in order to understand how active-learning instruction might impact student learning and retention in different classroom contexts.

Gasiewski and colleagues (2012) found that, while interactive teaching strategies were popular among student participants of their study, overall it was the instructor's attitude, knowledge base, level of enthusiasm, and ability to explain content clearly that were most influential to students' levels of engagement in STEM courses, even when traditional lecturing served as the primary vehicle for conveying course content (p. 247). Similar to Bryson and Hand (2007), Gasiewski et al. (2012) observed that the extent to which students perceived course instructors as either welcoming or distancing greatly impacted their level of student engagement; students were more engaged in classrooms where instructors were perceived as attentive and accessible, and less engaged in classrooms where instructors were perceived as unhelpful and/or unavailable to students. Student participants also reported feeling less engaged in courses where instructors reported having insufficient time to provide individualized attention to their students. Gasiewski and colleagues concluded that "if students perceive faculty to be uncaring, unengaged, or unavailable to help them succeed in learning, they may disengage from the course" (p. 248). Based on these findings, Gasiewski and colleagues suggest that the traditional lecture format may not itself be a problem, but rather a combination of the learning environment and the behaviours and strategies used by instructors of introductory STEM courses that may be responsible for low levels of student engagement in these contexts. Sfard (2014) explains that, while this style of teaching may be subject to criticism from researchers *outside the discipline(s)*, the traditional chalk and talk style of lecturing is optimal, if not the only way to teach mathematics at the university level. The following section reviews research on university mathematics lecturing, including the teaching practices of university mathematics instructors, and factors shown to be influential to student engagement in the chalk talk context.

4.4 Previous Research on University Mathematics Lecturing

Traditional chalk talk lecturing is the primary means of teaching mathematics to students in university (Artemeva & Fox, 2010, 2011; Fox & Artemeva, 2012; Greiffenhagen, 2014; Speer, Smith, & Horvath, 2010), typically coupled with tutorials and problem-solving sessions (e.g., Artemeva & Fox, 2011). As mentioned, the usefulness and effectiveness of traditional lectures have been questioned, in part, because they seem to be lacking active-learning strategies (e.g., Bligh, 1972; Lew, Fukawa-

Connelly, Mejia-Ramos, & Weber, 2016; Yoon et al., 2010), and calls for active-learning strategies to be incorporated into university mathematics teaching abound (Auerbach et al., 2018). However, despite advances in teaching technologies, the prevalence of online learning forums, and access to materials online, lectures remain fundamental to the teaching of university mathematics (Speer, Smith, & Horvath, 2010; Wood et al, 2007). Additionally, empirical research has shown that undergraduate students not only attend university mathematics lectures (Bergsten, 2011; Cretchley, 2005; Hubbard, 2007), but also value lectures for their usefulness and sense of community and interaction, and view them as a highly important resource for learning (Bergsten, 2011; Cretchley, 2005; Hubbard, 2007; Pritchard, 2010; Rodd, 2003; Wood et al., 2007). Nonetheless, the debate continues (Pritchard, 2015), perhaps fueled by a continued lack of empirical research on university mathematics lecturing (Iannone & Miller, 2019; Viirman, 2015) despite numerous explicit calls for research of this kind (e.g., Speer, Smith, & Horvath, 2010). After conducting a comprehensive, systematic review of empirical research literature of tertiary mathematics teaching, Speer, Smith, and Horvath (2010) concluded that, while there exists a large body of research focusing on K-12 mathematics education (e.g., Fredricks et al., 2016; Gerofsky, 2004; Handal et al., 2012; Wagner & Herbel-Eisenmann, 2008; Wang et al., 2016), post-secondary mathematics teaching practices (i.e., what instructors say and do while teaching university lectures) remain largely unexamined. In the years following their 2010 call for more research on this area, there have been a handful of studies conducted in response, focusing either on the teaching practices of university mathematics instructors (e.g., Artemeva & Fox, 2011; Greiffenhagen, 2014; Fogarty-Bourget, 2013; Fox & Artemeva, 2012; Paoletti et al., 2018; Viirman, 2011, 2014) or on students' learning in university mathematics lectures (e.g., Lew et al., 2016) or both (e.g., Iannone & Miller, 2019). I review these studies in the following subsections beginning with a discussion of university mathematics discourse.

4.4.1 University mathematics lecturing: From discourse to embodied practice

As mentioned, mathematics has been identified as a distinct discourse (e.g., O'Halloran, 2005; Sfard, 2014; Wood et al., 2007). Sfard (2008), who developed the commognitive approach which views mathematics as discursive activity, describes "university mathematical discourse" (Sfard, 2014, p. 200) which, as she explains, is fundamentally new to the first-year student transitioning from high school into university. From a discourse studies perspective, university mathematics lecturing is highly interesting because it combines thinking, writing, talking, and movement in such a way that cannot be teased apart (see Fox & Artemeva, 2012). For those outside the mathematics discipline, however, it may be difficult to understand mathematics as such. To facilitate this understanding, Sfard takes the notion of thinking-as-self-communication as a starting point (drawing on the teachings of Vygotsky and Wittgenstein) and describes the thinking process of a solitary individual attempting to solve a mathematical problem. Sfard explains that in this scenario, the individual asks herself questions, pauses, reflects, and gives herself praise for arriving at the correct solution, all things that individuals do when engaging in a discourse. As any mathematician can plainly attest, thinking mathematics does not become *doing* mathematics without writing (see MacKenzie & Barany, 2014). This is not to be confused with the writing of mathematics research papers (e.g., Burton & Morgan, 2000), but rather the written representation of mathematical (abstract) thought. Greiffenhagen (2014) investigates the written discourse of mathematics, specifically, doing mathematics with chalk on a blackboard as a physical means of representation. He suggests that “thinking in mathematics is inextricably interwoven with writing mathematics” (p.523) and in this way “doing mathematics” is “‘thinking with eyes and hands’” (p. 502; see also Latour, 1986). To understand a complex mathematical argument, it must be made *visible* in order to see how all the parts are connected; by writing the argument down the writer makes it “inspectable” (Greiffenhagen, 2014, p. 526). MacKenzie and Barany (2014) also investigate the role of chalk and chalkboard in the presentation of mathematical argumentation focusing on advanced mathematics seminar performances. Doing mathematics on the blackboard, they explain, is a means of “publicly materializing mathematical concepts” (p. 25). Viirman (2014, 2015) adopts Sfard’s (2008) commognitive approach, and thus, like Sfard, Viirman (2014, 2015) operates on the premise that all mathematical concepts are discursively constituted, that is, they are written and/or spoken into reality (p. 513). In a university mathematics teaching context, the instructor writes and talks the mathematical concepts into reality, and in doing so, she is not just creating a physical (inspectable) representation of the abstract concepts, she “makes visible the process of mathematical reasoning” (Greiffenhagen, 2014, p. 521). Instructors make visible the thinking (and thus the *doing*) process through writing, as well as all the “pointings, tappings,” and “rubbings” (MacKenzie & Barany, 2014, p. 9) that go along with the written chalk talk performance. Thus, university mathematics lecturing brings together mathematical discourse and “natural language” (Wood et al., 2007, p. 911) with multiple modes including writing, speech, mathematical symbolism, image, movement, and gesture (Fox

& Artemeva, 2012; O'Halloran, 2005). By making seen and heard the process of doing mathematics through multiple discursive representations and communicative modes, the lecturer "personifies" the content of her lecture (Wood et al., 2007, p. 914). The teaching of university mathematics, in this way, is a multimodal, *embodied* practice (Fox & Artemeva, 2012).

4.4.2 Empirical research on university mathematics lecturing

To investigate the genres used in the teaching of university mathematics, Artemeva and Fox (2010, 2011) conducted a large-scale, international exploratory study of university mathematics instruction. They observed and video-recorded 33 undergraduate lecture classes presented across seven countries and conducted interviews with and collected field notes and instructional artifacts (e.g., teaching notes) from 50 participants (novice and experienced faculty with different cultural, linguistic, experiential, and educational backgrounds). The research revealed that all the instructors that participated in the study enacted the same teaching genre across all local, geographical, and institutional contexts. Artemeva and Fox (2011) identified the typified and recurrent way of teaching university mathematics as *chalk talk* (p. 345), which is enacted by university instructors through various embodied practices, often performed concurrently (see also Fox & Artemeva, 2012). These include writing on the board while articulating what they write[15] (i.e., providing commentary), turning to the students and talking about what they have written (i.e., metacommentary), moving around the room,

[15] Referred to by Greiffenhagen (2014) as "writing-talking", which he describes as instructors "writing things on the board while simultaneously saying them aloud" (p. 506).

drawing, diagramming, gesturing to students and at the board, asking questions and talking to the students, referring to their notes, and so on (Artemeva & Fox, 2011, p. 26). They also observed some subtle differences between participants' enactments of the genre, most notably in the way the participants connected emotionally with their students (discussed further in Section 4.4.3). Viirman (2014, 2015) conducted a similar but much smaller-scale study to investigate the teaching practices of seven Swedish university instructors teaching first-year mathematics lectures on the topic of functions. Using video recordings of the participants lecturing, Viirman applied Sfard's (2008) commognitive framework to analyse the discursive practices of the participants. The analysis revealed that the teaching of the lectures was operationalized through a set of "didactical routines". Three main routines were identified in the study: "explanation", "motivation", and "question posing" (Viirman, 2015, p. 1171). Viirman observed that the participants used various pedagogical devices to gain students' attention and facilitate their comprehension. Additionally, the participants of Viirman's study employed specific types of dialoging and question posing to keep the students engaged and active, and importantly, "involved in the actual process of doing mathematics" (p. 1779). Viirman did notice some differences, however, in the ways that participants in the study used the pedagogical devices and the extent to which they did so while teaching. While Viirman (2014, 2015) did use video data for the studies, and observed the routinized use of gesture in the teaching practices of the participants, he did not focus on the use of gestures in these publications.

While numerous studies have focused on the role of gestures in the teaching and learning of mathematics in elementary school contexts (e.g., Alibali et al., 2013; Alibali

& Nathan, 2012; Goldin-Meadow, 1999; Goldin-Meadow & Alibali, 2013; Goldin-Meadow et al., 2001; Roth 2001), there are only a few studies that offer such detailed investigations of university mathematics teaching (e.g., Fogarty-Bourget, 2013; Fogarty-Bourget, Artemeva, & Fox, 2019; Fox & Artemeva, 2012). Weinberg, Fukawa-Connelly, and Wiesner (2015) conducted a case study to investigate the use of gestures in university mathematics teaching, specifically as they are used to represent mathematical ideas (cf. Fogarty-Bourget, 2013). They analysed video data drawn from a corpus of six recorded introductory algebra lectures taught by an experienced university mathematics instructor. Their analysis revealed that the instructor used speech, writing, and gesture to create complex semiotic bundles used to convey mathematical ideas to the students. Their results support the findings of research on the use of teachers' gestures in K-12 classrooms that suggest the interaction between text, speech, and gesture, can enhance students' understanding of mathematical concepts in the classroom (e.g., Alibali et al., 2013; Goldin-Meadow & Alibali, 2013).

Fox and Artemeva (2012) were among the first researchers to undertake a large-scale multimodal investigation of university mathematics lecturing. Analysing video data collected from their global study of chalk talk lecturing (Artemeva & Fox, 2010, 2011), they observed that the chalk talk genre is, in fact, a multimodal pedagogical genre, enacted, in part, through the physical positioning of the instructor (p. 90). Specifically, the instructors in their study were observed using different bodily orientations to perform different communicative functions while lecturing (i.e., facing the chalkboard while writing mathematical notation, doing a half-turn toward the students to talk about what was written, turning completely to face the students while checking). While all the participants in their study used the same routines of movement, novice instructors were more likely to orient themselves towards the board for a higher percentage of the lecture time than more experienced instructors. I observed the same phenomenon in my Master's study (Fogarty-Bourget, 2013).

My Master's thesis (Fogarty-Bourget, 2013) presented a qualitative multimodal investigation of the strategies used by instructors of university mathematics to elicit feedback and participation from students. The participants were two instructors: a TA with 7 years of experience teaching in Canada and an experienced professor with decades of experience teaching in the United states. Using video recordings of the participants teaching mathematics to undergraduate students, I conducted a multimodal analysis of their verbal and nonverbal behaviours with a focus on interactive gestures (Bavelas et al., 1992; Kendon, 2004), body movements and orientation, gaze directionality, and speech. Results of the study showed that, despite differences in years of experience teaching, geographical location, and institutional context, both participants used remarkably similar strategies to elicit feedback and participation, including similar body positioning, eye movements, and gestures. One such strategy was the use of a partial or full turn towards the students, sometimes unaccompanied by speech, to signal to students that a response was required (see also Fogarty-Bourget, Artemeva, & Fox, 2019; Fox & Artemeva, 2012). The study also revealed subtle differences between the teaching strategies used by the TA and the professor including differences in the amount of time they spent facing the chalkboard versus looking at the students (discussed further in Section 4.4.4). Other differences were observed between the two participants such as the ways they portrayed their professional identities, related to the students, and demonstrated confidence in teaching (cf. Fox & Artemeva, 2012; Viirman, 2015). Even though the study was limited by a small sample size, the research highlighted the extent to which chalk talk is a highly interactive form of teaching in which the instructor and students are continually involved in an ongoing dialogue. This observation stands in opposition to claims made by some researchers that university mathematics lectures are dull, disembodied, and lacking in interaction (e.g., Gerofsky, 2010; Yusof & Tall, 1998).

Empirical studies of chalk talk that have been conducted from a multimodal perspective are particularly useful for understanding the interactional quality of the teaching and learning that takes place in the university mathematics classroom (e.g., Fogarty-Bourget, Artemeva, & Fox, 2019; Fox & Artemeva, 2012). For instance, Greiffenhagen (2008) makes a case for the usefulness of video-ethnography as a method of investigating university mathematics teaching. Using a case study of an instructor teaching graduate lectures in mathematics, Greiffenhagen demonstrates that teaching university mathematics "is predominantly not talking 'about' mathematics, but actually 'doing' mathematics at the board by going through established proofs for the student audience" (p. 12). Greiffenhagen differentiates between the formal representation of mathematical notation written on the board and the "embodied and vernacular" articulation which also captures the "main idea" of the mathematics being done (p. 24). Using the video-ethnography approach, Greiffenhagen is able to capture the richness of the lectures, namely the embodied formulation which is more "vivid" and "intuitive" than the written formulation alone (p. 24). He concludes that while mathematics is in a sense an abstract activity, the way a university lecturer presents these concepts to the student audience is very much an "embodied and situated" activity. Using video data, Greiffenhagen suggests, allows the researcher to uncover the "taken-for granted, seen but unnoticed aspects" of the genre (p. 27). As Fox and Artemeva articulate, "When only talk and writing are addressed in research, much of the actual pedagogical value of the chalk talk lecture is missed" (p. 97). The next subsection reviews empirical research that focusses more narrowly on aspects of teaching and learning mathematics at the post-secondary level, such as specific pedagogical practices used by instructors and characteristics of the learning environment related to student engagement.

4.4.3 Face-to-face teaching and interactional learning

As the studies reviewed in the previous subsection demonstrate, multimodal research on chalk talk lectures reveals a significant degree of student-instructor interaction involved in the teaching of university mathematics. A study of university mathematics teaching conducted by Iannone and Nardi (2005), who collected qualitative data from interview and focus-groups, presented similar findings. To investigate the teacher thought processes involved in teaching university mathematics, the researchers conducted 6-month study in which qualitative data were collected from 20 mathematician instructor participants from six different university departments across the UK. The data were collected using focus-group interviews wherein data-set booklets were distributed to participants in order to spur discussion around key issues surrounding the learning of mathematics at the university level. The data were analysed using grounded theory (Glaser & Strauss, 1967). Iannone and Nardi's (2005) findings touched on a range of pedagogical topics, but a theme that ran throughout the entire data collection period was the importance of learning university mathematics through interaction. According to the results of their study, the primary purpose of university mathematics teaching is to introduce students to the form and content (i.e., speech genre [Bakhtin, 1986]) of university mathematics (p. 195) (see also Sfard, 2014). The instructor participants of their study stressed that "learning mathematics is better achieved as a discursive endeavor" and spoke to what one participant referred to as different "language modes" of university mathematics (p. 198). These include the formal language of written mathematics (in textbooks and homework questions); the language of chalk talk that merges formal language with natural language (see also Wood et al., 2007) with the aim of exposing the formal material to students; and the informal, plain language that occurs in one-to-one interaction in meetings between students and instructors or students and peers. Part of instructors' role in introducing students into the university mathematics discourse is to facilitate students' understanding of the transition from concrete formal language into abstract mathematical ideas (Iannone & Nardi, 2005). These findings were supported by a multimodal study conducted by Wood and others (2007) who used video data to investigate the teaching practices of university mathematics lecturers and their students' learning of the material. In addition to video recordings, they collected other multimodal components of a "typical" undergraduate mathematics lecture including overhead transparencies and lecture notes (p. 909). They observed that the different modes of mathematical representation (e.g., writing, verbalizing, and gesturing) (cf. Iannone & Nardi, 2005) are important for student learning but even more important are the transitions or "links" (Wood et al., 2007, p. 907) between these modes of representation. In line with Iannone and Nardi (2005), Wood and colleagues suggest that a central purpose of lectures is to make obvious for students the links between the abstract mathematical concepts, the written representation of the concepts (available in notes, textbooks, and online resources), and the embodied process of doing mathematics in real-time. It is these links that the authors suggest are fundamental to students' learning of undergraduate mathematics. They explain how the lecturer is central to this process:

> In mathematics, abstraction is central, so the lecturer's personal mediation helps learners connect to the abstract nature of the subject through its multiple representations. The emotional connection between lecturer and student body is important and not only the lecturer's representations but also the transitions play an important role in learning in lectures. The transitions can be fleeting, like eye contact, significant pauses, arm gestures (such as vectors) and personalized stories, images, models and metaphors. (p. 914)

The study by Wood and colleagues demonstrates the value of multimodal inquiry particularly for shedding light on the richness of face-to-face chalk talk lecturing including some of the subtle or more nuanced qualities that can only be captured using video data. The study also highlights the inherent value of face-to-face lectures, specifically the role of the instructor for a) introducing students (i.e., novices) to university mathematics discourse and b) providing support, personal mediation, expertise, and instruction tailored to meet the needs of the students seated in the classroom. Bergsten (2011, 2012) arrived at similar conclusions after conducting a case study to understand students' reasons for attending lectures. The student participants of the study were one group of 141 engineering students studying industrial economy, and one group of 132 students studying physics and electrical engineering. The instructor participants of the study were two experienced lecturers running a calculus course for engineering students. Quantitative data were collected from students' responses to questionnaires (developed by Bergsten [2007] to assess the quality of undergraduate mathematics lectures) and qualitative data were collected using video recordings of the lectures and interviews with the student and instructor participants. Reporting on the results of the questionnaire, Bergsten (2011) found that students attended lectures because they found it easier to understand the mathematical content of the course from a lecture and because of the importance of teacher immediacy (Frymier, 1994), or instructor behaviour that implies closeness in teacher-student interaction in the classroom[16]. Bergsten (2012) concluded that the "complexity and richness of different educational aspects" of the chalk talk lecture as a way of teaching, including mathematical explanation, quality of instruction, and teacher immediacy, "contribute to its 'success' from the students' point of view" (p. 174).

As mentioned above, more recently, the need for face-to-face chalk talk lecturing has been called into question, particularly with increasing access to online resources including recorded or streamed lectures (see Bergsten, 2011; Hubbard, 2007). Howard, Meehan, and Parnell (2018) conducted a case study of a first-year mathematics module

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[16] Teacher immediacy has been described as a communication variable that contributes to students' sense of student-instructor closeness. Non-verbal teacher immediacy includes behaviours such as smiling, gesturing, eye contact, demonstrating expressiveness, directing physical orientation and narrowing proximity towards students. Verbal immediacy behaviours include using humour, inclusive language (e.g., "we" versus "I"), personal examples and asides, encouraging student contributions, addressing students by name, asking questions and being available for discussion (Frymier, 1994; Furlich & Dwyer, 2007).

(component of a course) offered at a university in Ireland to undergraduate business majors. The module gave students a choice to complete the course using short online videos, face-to-face (live) lectures, or a combination of the two resources. The researchers collected quantitative data of usage and attendance statistics from 522 students enrolled in the course and qualitative data from surveys about student perceptions of resource usage gathered from 161 students at the end of the semester. The analysis revealed four distinct usage types across the student sample: video users, lecture users, dual users (students who used both resources in a complementary manner), and switchers (those that switched resources but with little overlap). Howard, Meehan, and Parnel found that students chose to attend live lectures for the following reasons: for classroom interaction (the ability to ask questions and discuss the material); to see the material covered in more depth and complexity; a sense that they were learning “automatically”; and to be better prepared for quizzes and exams. Students chose online videos for reasons of flexibility, to be able to pause and rewind videos (i.e., concerns regarding pacing), and schedule considerations. The researchers concluded that, while students generally had positive perceptions towards online learning, the results did not suggest that online learning was superior; in fact, students in their study who attended live lectures achieved, on average, higher final grades than those who did not attend lectures (pp. 547-548).

As briefly discussed in Section 4.3, in face-to-face teaching contexts, students are more engaged when learning from an instructor who is perceived as attentive, enthusiastic, and supportive (Cretchley, 2005; Gasiewski et al., 2012). As research by Wood and others suggests (e.g., Artemeva & Fox, 2010; Wood et al., 2007;) the character an instructor plays while teaching and the degree to which they connect emotionally with their students, described by Artemeva and Fox (2010) as the "teaching persona", directly affects the atmosphere of the learning environment, as well as student learning and engagement (pp. 177-179). Artemeva and Fox explain that instructors can portray a persona that is "welcoming" (using humour, being personable, supportive, and available to students) or "distancing" (conveying excessive formality, a general lack of warmth, or by scolding students) (p. 177). From the data they collected during classroom observations, Artemeva and Fox concluded that, as a result of the teacher persona generated by the instructor, classroom atmospheres could range "from 'icy' to 'warm and relaxed'" (p. 178). These findings are in agreement with research by Gasiewski and colleagues (Gasiewski et al., 2012), however, it is important to note that Artemeva and Fox (2010) focus on university *mathematics* lecturing specifically rather than STEM disciplines in general (cf. Gasiewski et al., 2012). The next subsection reviews empirical research on teaching practices and instructor behaviour in the university mathematics classroom.

4.4.4 Teaching practices and instructor behaviour

Because the extent to which instructors are perceived by students as attentive, approachable, and cooperative depends largely on their verbal and nonverbal behaviour in the classroom (e.g., Wubbels & Brekelmans, 2005), and because research on university mathematics teaching has shown differences in the ways that novice and experienced instructors interact with students (Fogarty-Bourget, 2013; Fox & Artemeva, 2012), some aspects of the teaching persona may be related to an instructor's teaching experience. For instance, in my Master's research (Fogarty-Bourget, 2013), I observed that the behaviours exhibited by the participants in my study reflected the types of behaviours that Wubbels and Brekelmans (2005) attributed to the effects of teaching experience. The very experienced professor in my study exhibited so called high influence behaviours (e.g., standing in front of the class, facing the students with the head held upright, speaking at a loud, clear lecturing volume, making eye contact with students, and scanning the classroom)--all to a greater extent than the less experienced TA. While teaching, the professor faced the class for 53% of time, whereas the TA faced the class for only 19% of the time (see also Fox & Artemeva, 2012). Furthermore, the professor was observed scanning the class in a "pan-gaze" 41% of the time, whereas the TA was observed scanning the class only 12% of the time. Pan-gazes typically coincide with instances of checking student understanding and attentiveness and posing questions to the students.

Of the research investigating pedagogical strategies for teaching university mathematics, questioning has been identified as one of the most common and effective ways instructors can engage students in learning (e.g., Lew et al., 2016; Mason, 2000; Paoletti et al., 2018; Querol-Julián & Arteaga-Martínez, 2019; Speer, Smith & Horvath, 2010). In an analytic reflection on his own university mathematics teaching, Mason (2000) suggests that by being mindful of the types of questions posed to students in undergraduate mathematics lectures, and the ways in which the questions are asked, an instructor can create an atmosphere that facilitates students' mathematical thinking, enriches students' experience of mathematics, and scaffolds their entry into the university mathematics discourse. Mason describes the critical process of scaffolding and "fading" (i.e., the gradual fading-away of the instructor's support) (cf. Vygotsky, 1987). Fading, Mason explains, allows the students to internalize the process of doing mathematics (as demonstrated by the instructor), and eventually, do mathematics independently. He suggests that one way to initiate fading is to move through a sequence of direct or focused questions (used for directing student attention) to more indirect prompts until students are spontaneously asking content-generating questions independently. The process is cyclical in that once students can independently comprehend the mathematics the instructor has been doing, the instructor can move on to demonstrating more sophisticated tasks, for which the students will again receive scaffolding and then the instructor will perform fading so the students transition to doing mathematics independently (pp. 99-100). The findings of a case study conducted by Speer (2008) lend support to Mason's (2000) observations. To investigate the ways in which teachers' beliefs about students' comprehension shape classroom interactions during problem-solving sessions, Speer (2008) collected rich, qualitative data using video-recordings of eight first-year calculus tutorials taught by a TA participant. During the tutorials, the students often worked in small groups to solve problems on blackboards which lined the walls of the classrooms; thus, the students' work was publicly visible and accessible, and there were many opportunities for student-instructor interactions throughout the class. In addition to the recordings, Speer conducted a series of nine audio-recorded "video-clip" interviews where segments of the video data were reviewed by the TA participant and discussed with the researcher. Speer found that the TA's beliefs about the nature of students' comprehension and learning of mathematics shaped the ways in which he responded to students' attempts at publicly doing mathematics in the classroom. In particular, the types of follow-up questions the TA asked the students in order to lead them to key ideas or correct interpretations of the material were shaped by his perspectives on learning. The TA believed that learning meant making connections (cf. Iannone & Nardi, 2005; Wood et al., 2007) between what was already known and new ideas, and that the essence of learning was evident when students were able to work on problems, struggle with ideas, have “epiphanies” and make sense of problems for themselves (Speer, 2008, p. 249; cf. Mason, 2000); thus, the TA felt that his primary mode of interacting with students should be asking questions (cf. Iannone & Nardi, 2005; Sfard, 2014). The TA believed that he could not make those connections for the students, but that the role of the instructor was to facilitate students’ understanding of the material, create opportunities for them to form the connections themselves, and provide scaffolding (pp. 248-250). Based on these beliefs, the TA responded to students attempts at doing mathematics by beginning with directed questions to focus students’ attention to particular points in the solutions, then, asks a series of less and less specific questions to move them in the appropriate direction, and facilitate the connection-making process. The decreasing specificity of the questions resulted in “increasing opportunities to access students’ ideas and understandings” (Speer, 2008, p. 240). These results provided further empirical support for Mason’s (2000) proposed strategy of teaching mathematical concepts by using question sequences designed for scaffolding/fading. The approach that Mason and Speer (2008) describe underlies the idea of the *Socratic* method of teaching, that is, a traditional method of teaching done primarily though dialoging between teacher and student (Rhee, 2007, p. 882; Polya, 1957, 1963). Polya (1957) suggested that mathematical problem solving can be learned through a framework of simple, thought-provoking and guided questions to lead students towards their solution by soliciting their contributions (guesses) at solving the problem. Polya (1963) presents the Socratic approach in reference to the "principle of active learning" wherein an instructor "Let[s] the students *discover by themselves as much as feasible* under the given circumstances" (pp. 608-609; emphasis in original). The aim of the method is to help the student solve the problem at hand but also, and perhaps more importantly, develop the student's ability to solve future problems independently (Polya, 1957, pp. 3-4; see also Rhee, 2007 on adapting the Socratic method for the undergraduate law-school classroom). Polya (1963) recommends that whenever possible, instructors should "let the students actively contribute to the formulation of the problem that they have to solve afterwards", reason being that "if the students have had a share in proposing the problem they will work at it much more actively afterwards" (p. 609).

Another pedagogical strategy related to questioning that has been linked to student engagement (Finn & Zimmer, 2012) is the use of wait-time (Rowe, 1971/1986), that is, of intentional pauses in talk while teaching. Rowe (1986) explained that there are two points in teachers' speech at which extended wait-time is most valuable: after posing a question (type 1) and after a student response (type 2). Rowe suggested that if instructors increased the average length of wait-time at both points to 3 seconds or more, there would be pronounced changes in student contributions and overall classroom climate (p. 44). Among these changes she listed increases in: the length and frequency of student responses, number of questions asked by students, student-to-student exchanges, diversity of student participation, and student confidence. Her results showed decreases in: students' failure to respond, signs of restlessness and inattentiveness, and "teacher-centred 'show and tell' behavior" (pp. 44-45). Rowe's research was conducted primarily in K-12 teaching contexts, however, there were some studies conducted in post-secondary lecture-based science courses (e.g., Rowe, 1980). Furthermore, the pedagogical importance of wait-time is well recognized in research on university mathematics education (e.g., Paoletti et al., 2018), particularly, as a resource for instructors to monitor student understanding and for students to ask questions and participate in class discussions.

Paoletti and co-authors (2018) investigated instructors' use of student-directed questions and wait-time in advanced mathematics lectures. The researchers examined the teaching practices of 11 instructor participants teaching at universities across the eastern United States using audio-recordings of 80-minute chalk talk lectures and transcripts of board-writing collected from classroom visits. To analyse the data, the researchers identified all instances where instructor participants solicited student participation during the lectures and then coded each question-answer sequence for wait-time and student response rate. They found that overall, lecturer questioning was common in advanced mathematics lectures with an average of 56 questions being asked per lecture, but that there was significant variance among the lecturers with one lecturer asking only 4 questions and another asking 202 (the other nine instructors asked between 15 and 90 questions per lecture). To be considered an "opportunity to participate", the questions posed by the instructor participants needed to be either responded to verbally (the study did not use video-data to observe nonverbal contributions) or to be proceeded by at least three seconds of wait-time. Based on these parameters, the researchers concluded that students were given limited time to respond to questions and limited opportunities to participate with content-generating contributions. However, in the study I conducted as part of my Master's research (Fogarty-Bourget, 2013), the instructor participants used extensive wait-time to elicit responses and participation from students, with some instances lasting for as long as 9 seconds. Interestingly, the TA in my study used longer pauses than the professor (7.5 seconds on average [TA] versus 2.5 seconds on average [professor]) and received more student responses (19 [TA] versus 7 [professor]). These results may support Rowe's (1986) findings that increased wait-time results in higher frequencies of student-responses, although, the increase in student responses may also have been a result of the professor using more effective classroom management strategies (i.e., having students raise their hands instead of shouting out answers).

Looking at live videoconferencing lectures of didactics in mathematics, Querol-Julián and Arteaga-Martínez (2019) investigated the ways in which two instructors of a professional master's degree course in Education managed silence to promote engagement with students participating online at a distance. Like other scholars (e.g., Jaworski, 2002; Sinclair & Coulthard, 1975) they identify an initiation-response-feedback cycle or "teaching cycle" wherein an instructor asks a question to the students, provides wait-time for students' responses, the student(s) respond, and feedback is provided (Querol-Julián & Arteaga-Martínez, 2019, p. 304). Their analysis revealed that the instructor participants in their study used silence as a means of engaging the students. However, they also noted that because the online-learning context made mutual feedback between the instructors and learners difficult, the instructors needed to deploy different strategies to repair their silence to keep the students engaged such as relying on various teaching materials with which to involve students in the course content.

Notably, Lew and colleagues (2016) suggested that students may still struggle with comprehension despite substantial opportunities to ask and answer questions. The researchers conducted a case study to investigate the extent to which students of an undergraduate mathematics course understood the key concepts the instructor of the course was trying to convey during lecture. Qualitative data were collected using video recordings of one lecture as well as follow-up interviews with the instructor, and focus-group interviews with six students held 3 weeks after the lecture. The researchers found that the student participants had trouble recalling the key points of the lecture based on their notes alone. Only after having watched the video-recorded lecture and re-watching highlighted segments were the students able to articulate the majority of the main points the instructor was trying to convey. The researchers provided several possible reasons for this outcome: first, students may come to acquire the key ideas of the course incrementally over time (this reason was also articulated by the instructor of the course during an interview); and second, the main note-taking strategy used by the students was to focus only on what the instructor had written on the blackboard and not the metacommentary he provided orally during the lecture, which was often used to convey key ideas.

Some researchers (e.g., Larwin & Larwin, 2013) have suggested that instructors incorporate the use of guided notes into their teaching of chalk talk lectures to facilitate students' comprehension of the material. Guided notes typically consist of pre-prepared -lecture notes with gaps in the content for students to fill in during the corresponding lectures. A recent case study by Iannone and Miller (2019) investigated instructors' use of guided notes in undergraduate mathematics lectures for facilitating students' understanding of the subject matter. They chose to focus on this “relatively small change” to chalk talk lecturing because the method of supplying guided notes still “respects the link. . ., between writing and doing mathematics” and some research has found the practice to be more effective than students’ own note-taking strategies for learning (p. 19). The researchers collected qualitative data from two rounds of interviews with an instructor of a first-year mathematics course and eight of his students and classroom observations of two lectures. Their results showed that supplying guided notes did impact the way the students recorded parts of the instructor’s verbal commentary that may have otherwise gone unnoticed. They also observed, however, that the use of guided notes did not necessarily help the students realize that the verbal comments made by the instructor were important and thus, used on their own, the guided notes did not make the pedagogical intentions of the lecturer any clearer for the students.

Some empirical research has focused on even more granular features of university mathematics teaching. Thus, Looney, Jia, and Kimura (2017) investigated a micro-feature of university mathematics discourse – the use of “okay” in undergraduate mathematics lecturing. To conduct the qualitative study, the researchers collected video recordings of three graduate student instructors teaching second-year calculus courses at a research university in the United States. They analysed four hours of each participants’ chalk talk lecturing by, first, identifying all instances of self-directed “okay” in the footage (100 instances in total), and, second, by describing the prosodic, sequential, and functional features of each instance as well as accompanying gaze, gestures, and other nonverbal resources used by the speaker. They found that instructors’ use of self-directed “okay” to be critical to the discourse structuring of lectures both for the students and for the instructor leading the lecture. Additionally, Looney, Jia, and Kimura's findings showed that such self-directed talk functions in this context as a resource for self-regulation and for maintaining student attention, and is an important part of the verbalization of the thought processes involved in teaching-by-doing mathematics (p. 47). They also identified a gap in research literature on pedagogical discourse stating that the majority of analyses had lacked close attention to nonverbal resources and called for more studies that use video data to support their analyses. This study makes evident the complex nature of chalk talk lecturing and instructors' self- and student-directed talk. Similarly, Iannone and Miller (2019) emphasize that university mathematics teaching is a highly complex area of study, in part, because, in addition to the teaching practices employed by instructors, the learning environment plays a significant role in all aspects of student learning.

4.4.5 The chalk talk learning environment

As previously discussed (Sections 4.3 and 4.4), there has been pressure to implement changes to university mathematics learning environments (Auerbach et al., 2018; Lew et al., 2016); at the same time, however, there is continued empirical support for traditional chalk talk lecturing as a valuable pedagogical resource (e.g., Bergsten, 2012; Howard, Meehan, & Parnell, 2018). As Rodd (2003) points out, the advocates for such contemporary pedagogical approaches as interactive teaching and/or active learning strategies tend to view university mathematics lecturing as outdated, transmission style teaching, in part, because students' participation in chalk talk lectures is not always realized through the same channels as in other disciplines. As part of a three-year collaborative project between a group of researchers studying the student experience in undergraduate mathematics, Rodd investigated the role of traditional mathematics lectures in introducing students into the mathematical community and the impact such lectures have on students' academic success. Rodd's paper draws on data collected from interviews with 19 first-year mathematics majors studying at two universities in the UK and classroom observations of the mathematics lectures and tutorials attended by the student participants. Based on these data, Rodd describes the undergraduate mathematics lecture as a theatrical (multimodal) performance and the chalk talk lecture theatre as a "site for participation of a special sort" (p. 20). On one hand, students attend lectures for the possibility of witnessing mathematics performed by an expert who is (ideally) an inspiring instructor and in this way each student becomes involved in the lecture as "participatory witness" (p. 21). On the other hand, students who attend lectures regularly, gather in the lecture theatre as a peer group, weekly and for the duration of the course (or longer), and in this way are involved in active-participation as members of their university mathematics community. Thus, Rodd demonstrates that the undergraduate mathematics lecture environment is, in fact, a site for joint-participation and enculturation into a particular discourse community.

In the research on university mathematics education reviewed thus far, there are repeated mentions of the pedagogical importance of writing on the board, and on the chalkboard, specifically, in the university mathematics lecturing context. Namely, that instructors' use of chalk and chalkboard allows students to see the process of doing mathematics unfold in real-time. However, for some, changes to university classroom layouts have meant an absence of suitable blackboard or whiteboard space for writing (cf. Maclaren, Wilson, & Klymchuk, 2018), and other changes to the learning environment related to the “massification” of higher education (Bergsten, 2012, p, 167) have put pressure on instructors to adopt various teaching technologies to deliver content more efficiently to growing numbers of students. Maclaren, Wilson, and Klymchuk (2018) conducted a qualitative study of the teaching practices of university instructors using pen-enabled tablet PC (penTPC) to teach lectures in undergraduate engineering, mathematics for engineering, and statistics courses. The researchers used video-recordings of lectures taught by 7 instructor participants to compare the teaching practices of their participants using penTPC with the “core elements of chalk talk” as described by Fox and Artemeva (2012, p. 33). They observed that the core components of chalk talk were present in the teaching practices of their participants, albeit in a modified form. They suggested that the augmented capability for annotation offered by the technology in conjunction with other digital representations in the penTPC environment has the potential to provide opportunities to enhance teaching. Conversely, Artemeva and Fox (2011) whose participants viewed the act of writing on the board as a “means of introducing students to the disciplinary thinking, practices, and procedures of ‘doing mathematics’” noted that the advantage of chalk talk, according to their participants, was “that it slow[ed] down the ‘doing’” (p. 357). Similarly, Greiffenhagen (2014) observed a strong preference for blackboards over other presentational devices amongst the mathematicians he contacted for his study of chalkboard use in university mathematics teaching. The mathematician participants listed many functional reasons for this preference, in particular, speed and visibility. Greiffenhagen explained that having to write out a solution on the blackboard slows the instructor down making it easier for the listener to follow the argument. Chalk talk, unlike other representational mediums such as textbooks, paper, slides, and tablets, "can only ever unfold at the pace of chalk sliding against slate", as MacKenzie and Barany (2014) articulate in their study of the professional practice of university mathematics seminar presentations, "the intrinsic necessity of bit-by-bit unfolding in mathematical exposition is thus built into chalk as its means of writing" (p. 14). One participant in Maclaren, Wilson, and Klymchuk's (2018) study abandoned using the penTPC citing problems related to student engagement, in particular, the tendency for the text to move around unlike writing on the board which is fixed. This is important to consider when teaching mathematics, as, according to Greiffenhagen (2014), the positioning of the writing on the blackboard also carries meaning: instructors typically designate particular regions of the board for specific purposes (cf. Artemeva & Fox, 2011). Although Maclaren, Wilson, and Klymchuk (2018) concluded that teaching technologies such as the penTPC are likely to enhance teaching, they noted several issues that resulted from participant adoption of the technology. These included a reduction in the use of pedagogical gestures, technical difficulties with operating the equipment, and, as one participant described, the formation of an interpersonal barrier between the students and the instructor who needed to continually look down while teaching in order to operate the device. These issues were not unpacked in the article but seem to suggest that more research needs to be done in order to understand the relationship between so-called "enhanced" teaching experiences and student learning and engagement.

Much of what impacts student engagement is said to involve factors that extend beyond the instructors and their teaching practices, such as characteristics belonging to the students themselves (e.g., Finn & Zimmer, 2012) including their beliefs, interests, and levels of motivation, as well as their strategies for participating in and interacting with the learning environment. There is a direct relationship between students' behaviour in the learning environment and their engagement in learning, and, as Iannone and Miller (2019) suggest, students' levels of comprehension and the resulting achievement. Research by Shernoff et al. (2017) showed, for example, that where students choose to sit in the lecture classroom had a significant impact on their sense of success and engagement in the course. The team of researchers conducted a quantitative study to investigate the influence of students' seating location in large, lecture-style university courses on student engagement, attention, classroom learning experience, and course performance. They used data collected from experience sampling surveys administered to 319 undergraduate students in an introductory financial accounting course to capture snapshots of students' engagement, attention, and other experiential variables while sitting at different classroom locations at multiple time-points during the semester. The results indicated that seating location and spatial proximity to the instructor, in particular, consistently affected multiple aspects of the student experience including having an influence on course performance and student engagement in the classroom (p. 63). Student participants who were seated at the back of the lecture hall reported feeling more distracted and less focused, as well as less successful, valued, connected and included than when sitting closer to the front of the room and the instructor; they also reported a negative emotional affect while sitting in the back. Student participants sitting in the front of the room, on the other hand, reported higher levels of participation, motivation, and enthusiasm. Another factor that has been shown to impact student engagement in university learning environments is students' academic major which can impact their level of interest and motivation for learning (Gasiewski et al., 2012; Jablonka, Ashjari, & Bergsten, 2016).

Mathematics departments typically offer undergraduate mathematics courses both to mathematics majors and to students in other disciplines such as physics, chemistry, engineering, and so on (Artemeva & Fox, 2011, p. 7; Flegg, Mallet, & Lupton; 2012). The student diversity that exists within the undergraduate mathematics classroom presents educators with a unique challenge when it comes to engaging students in lectures (Flegg et al., 2012). As an experienced mathematics educator, Professor Neufang (personal communication, February 23, 2016) stressed that instructors need to adapt their teaching strategies accordingly when teaching to students from other disciplines who, unlike mathematics majors, are not as inherently interested in the mathematics itself. Like other experienced mathematics educators (e.g., Amundsen, personal communication, July 12, 2016), Professor Neufang identifies undergraduate engineering students as notoriously “tricky” to engage in lectures because of their shared tendency to view their required mathematics courses as “a means to an end”. In addition to this anecdotal evidence, there has been empirical research to suggest that engineering students view mathematics differently and value (or do not) mathematics for different reasons than do students from other disciplines (e.g., Cardella, 2008; Croft & Ward, 2001; Flegg et al., 2012). Additionally, because engineering students are said to be impacted by the “gatekeeper” effect of introductory mathematics courses to a greater extent than some other groups of students (e.g., Gasiewski et al., 2012; Jablonka et al., 2016), they represent a unique participant sample on which to focus. My study involves engineering students as participants. The study participants are further discussed in the next chapter (Chapter 5, Section 5.3).

4.5 Research Questions Revisited

On the basis of the combined theoretical and analytical framework (Chapter 2), conceptual discussion of student engagement (Chapter 3), and review of relevant research literature (Chapter 4), I expanded my initial research questions presented in Chapter 1. In particular, I added an additional question to address the factors within the classroom context (i.e., the learning environment and classroom climate) which may impact student engagement in chalk talk lectures. My revised research questions are as follows:

1) What constitutes student engagement in the university mathematics lecturing (chalk talk) context? How can it be defined?

2) What aspects of the chalk talk classroom context affect student engagement? What facilitates student engagement in this context? What makes student engagement difficult?

3) What strategies do university mathematics instructors use to help realize student engagement in chalk talk lectures?

In order to respond to the research questions, I conducted a study of chalk talk mathematics teaching in several English-medium universities in three countries with English as an official language (referred to as Country A, Country B, and Country C).

Study design and methods of data collection and analysis are presented in the next chapter (Chapter 5).

Chapter 5: Methods

To seek responses to the research questions presented above, I used a mixed methods research methodology. In mixed methods research, the researcher collects and analyzes quantitative and qualitative data and “mixes (or integrates or links) the two forms of data”, giving “priority to one or both” in a single study (Creswell & Plano Clark, 2011, p. 5). The benefit of mixed methods, as Moriarty and colleagues (2019) point out, “is that it enables scholars to draw out the empirical data . . . by making use of both quantitative and qualitative data and methods” (p. 16). The study consists of two phases and is conducted from a pragmatic perspective, wherein by pragmatism I understand a research perspective, which, according to Creswell and Plano Clark (2011) is problem-centred and focused on the primary importance of the research question(s) (p. 41). This perspective is pluralistic in nature and draws on theory to help explain phenomena while acknowledging that reality is socially co-constructed and thus multiple interpretations of reality exist (p. 46). From this pluralistic stance, throughout the research process and in the construction of the final narrative I have analysed different types of data best suited to answer my research questions and drawn on multiple viewpoints.

This chapter begins with a discussion of the unit of analysis[17] followed by an overview of the study design and ethics approval. I then report on the participants, research sites, the nature of data, and methods of data collection and analysis. The chapter concludes with a discussion of triangulation methods and trustworthiness of the study.

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[17] As discussed in the following section, I have selected a unit of analysis for the overall study and multiple sub-units of analysis for different phases of inquiry.

5.1 Unit of Analysis

The unit of analysis, as defined by Geisler (2004), is that which "identifies the level at which the phenomena of interest occurs" (p. 29); it the smallest indivisible unit which "retains all the basic properties of the whole and which cannot be further divided without losing them" (Vygotsky, 1962/2000, p. 4). As Matusov (2007) suggests, the unit of analysis must always be shaped by "the purpose of the researcher and the material of the study" (p. 308). As mentioned in previous chapters (Chapters 1 and 2), the theoretical and analytical framework of this study draw on sociocultural theories of discourse and learning (e.g., Bakhtin, 1986; Miller, 1984, 2015; Norris, 2004, 2011; Rogoff, 1991; Scollon, 2001; Vygotsky, 1987). Echoing Vygotsky (1987), Räisänen (2015) makes the important point that, "the implication of these perspectives for studies of discursive practices is that the unit of analysis cannot be reduced to only actors, social contexts, or mediating tools. Rather, practice or activity needs to be viewed as social practice" involving the interaction of social actors, contexts, and objects, and the environment (p. 134). My phenomenon of interest being student engagement in undergraduate chalk talk lectures, I have selected the *system of classroom practices in an undergraduate mathematics course* as my unit of analysis for the overall study. In line with Matusov, however, I view this unit of analysis as "partial, incomplete and open" and "part of a bigger system" (pp. 326-27). Because the study investigates the phenomenon of interest from multiple perspectives (that of undergraduate students and the instructors who teach them) and draws on different types of data and mixed methods methodology, which allows me to combine quantitative and qualitative phases, I use several sub-units of analysis, described below, to address each research question.

5.2 Study Design

To conduct the investigation, an explanatory sequential design (Creswell & Plano Clark, 2011) was used wherein the results of an initial, mixed methods phase of data collection and analysis (Phase 1) were used to respond to the first research question and inform a second, qualitative phase (Phase 2) (Figure 1).

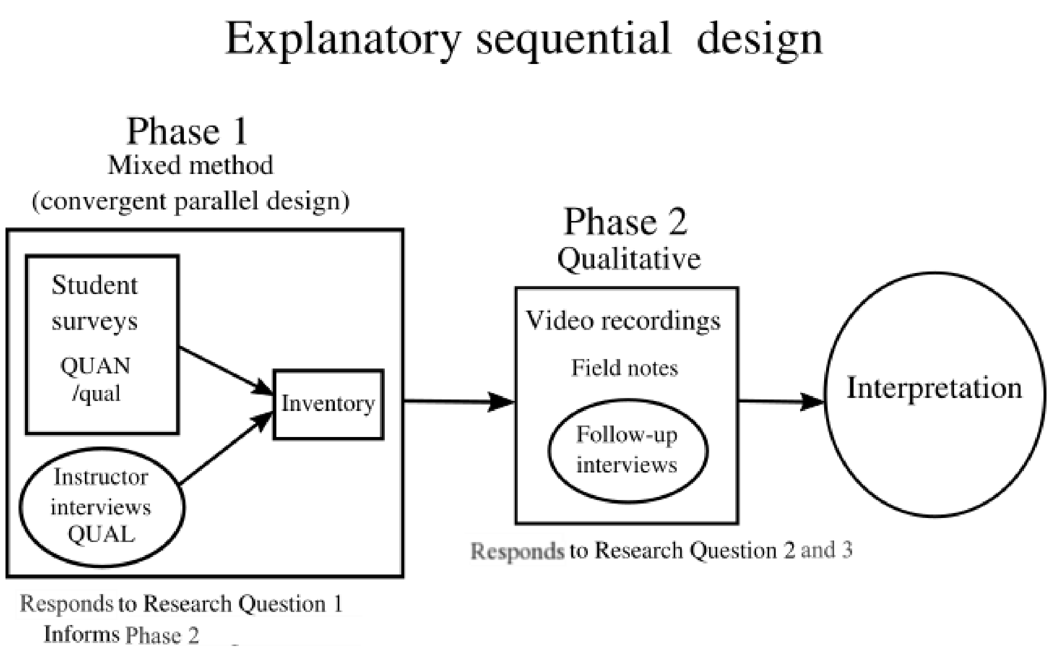

Figure 1. Study design (Creswell & Plano Clark, 2011).

In Phase 1, a survey (Appendix A) was administered to undergraduate engineering students who have taken mathematics courses, with student responses analysed quantitatively and qualitatively, and two-part interviews were conducted with undergraduate mathematics instructors and analysed qualitatively (see Appendix B for interview materials). The results of Phase 1 furthered my understanding of the concept of student engagement in the chalk talk context and helped to answer the first research question (*What constitutes student engagement in the university mathematics lecturing (chalk talk) context? How can it be defined?*). As well, the results informed the development of an inventory of *instructor traits and behaviours* related to student engagement. In Phase 2, video recordings of university mathematics lectures were collected along with field notes and post-recording follow-up interviews with instructors. The multimodal (video) data were analysed concurrently with the interview data, and the results were used to respond to the second research question (*What aspects of the chalk talk classroom context affect student engagement? What facilitates student engagement in this context? What makes student engagement difficult?*) and the third research question (*What strategies do university mathematics instructors use to help realize student engagement in chalk talk lectures?*). Overall conclusions were drawn by merging the outcomes of both phases.

5.2.1 Phase 1 study design

In Phase 1 (Figure 2), a convergent, parallel design was used to achieve a holistic understanding of student engagement in chalk talk lectures and develop a context-specific definition of the phenomenon. Phase 1 combined two strands of data collection and analysis: a mixed method strand in which quantitative and qualitative survey data were collected from student respondents (SRs), and a qualitative strand in which qualitative data were collected from two-part semi-structured interviews with instructor participants (IPs). By administering surveys to SRs enrolled in first-year, core undergraduate mathematics courses in Country A, and conducting two-part interviews with IPs, I was able to include multiple perspectives, those of students and instructors, in my research. The quantitative and qualitative data were collected and analysed concurrently and results merged to respond to the first research question and establish a final inventory of engagement constructs (aspects that contribute to the overarching construct of student engagement) and instructor traits used to inform the second phase of the study.

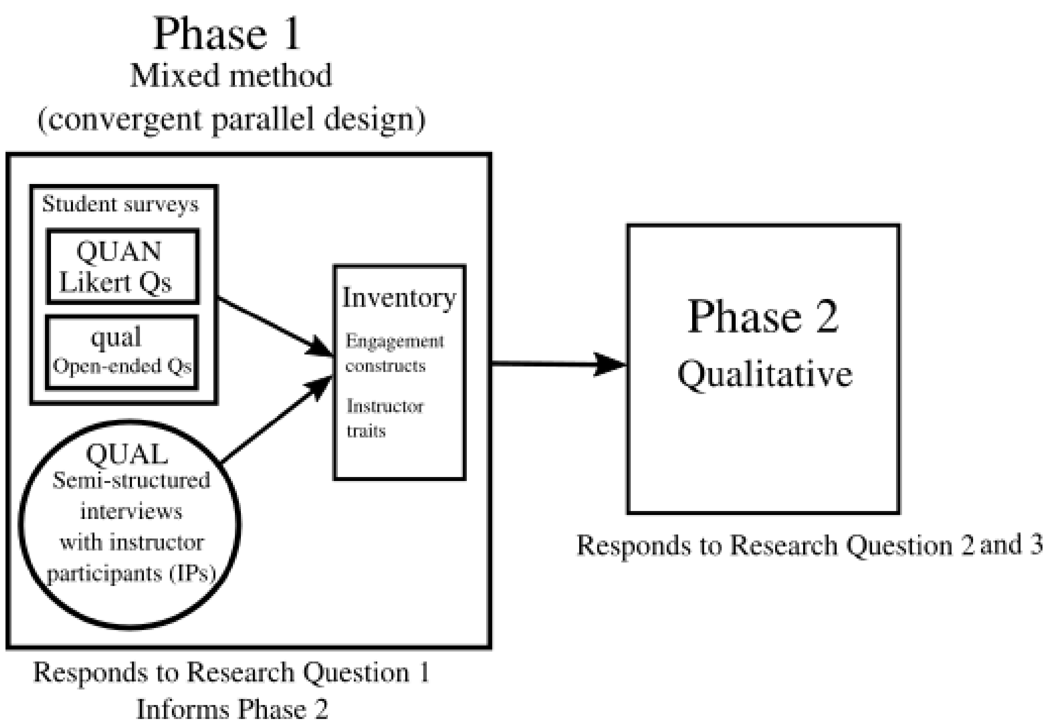

Figure 2. Details of Phase 1 study design.

5.2.2 Phase 2 study design

Phase 2 of the study (Figure 3) was conducted using qualitative methodology. To investigate aspects of the classroom context and the strategies used by university mathematics instructors to facilitate student engagement in chalk talk lectures, video-recordings of lectures and observational field notes were collected from university mathematics courses taught in Country A and Country B. Follow-up semi-structured interviews were conducted with the IPs after the lectures were recorded. Next, in order to establish a video corpus of lectures taught by IPs ranging in experience and teaching in different geographical and institutional contexts, the video data were combined with video-recorded lectures collected as part of a large-scale international study of university mathematics lecturing conducted by Artemeva and Fox[18] (2010; see also Artemeva & Fox, 2011; Fox & Artemeva, 2012). Informed by the interpretations of the Phase 1 results, the video and interview data were analysed concurrently and the results were merged to respond to the second and third research questions.

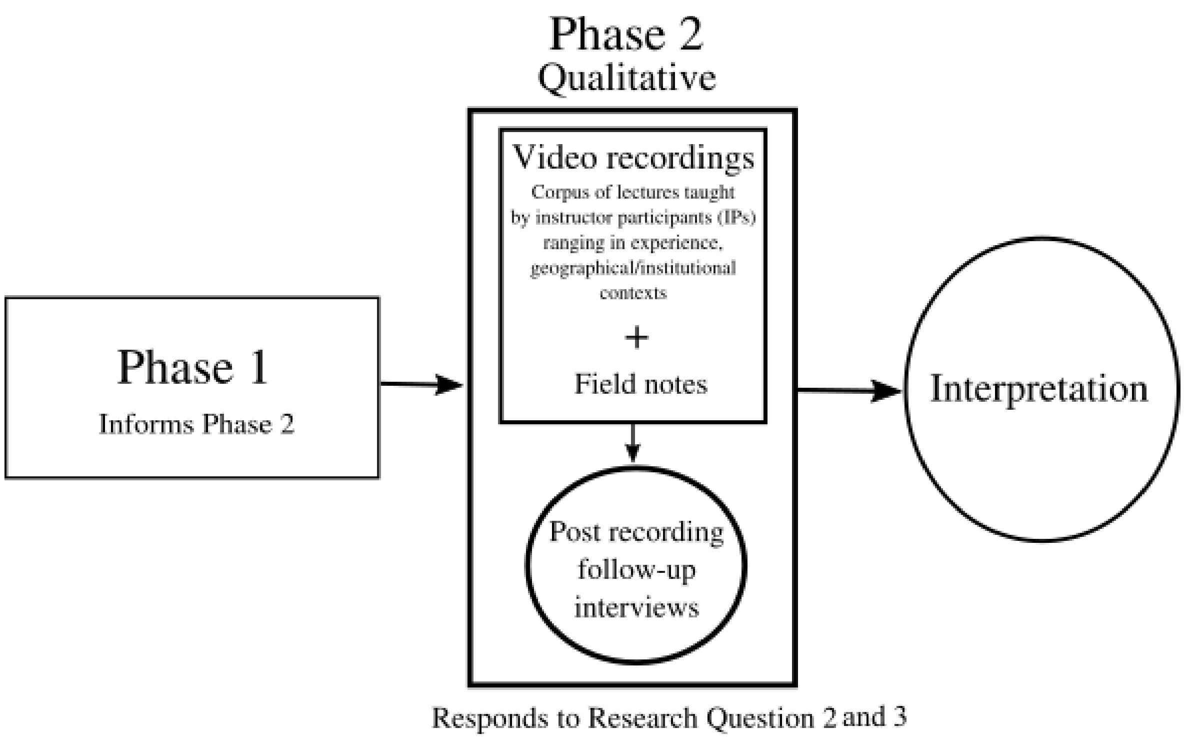

Figure 3. Details of Phase 2 study design.

[18] I have been involved in this research first as a Research Assistant and later as a Co-investigator.

5.2.3 Ethics

Ethics approval for the student survey stage of the study (Phase 1) was granted by the Research Ethics Board of the Country A university in May 2016. Ethics approval for the interview (Phase 1 and 2) and video recording (Phase 2) stages of the study was granted by Research Boards of the Country A university (in February 2017) and the Country B University (October 2018). Permission was obtained to reproduce the likeness of the IPs in the dissemination of this research. For the majority of the IPs, permission was obtained to reproduce their likeness using video clips, photographs, or screen grabs, however, some IPs opted to only be represented using line drawings. Original ethics approval for the large-scale international study of university mathematics lecturing conducted by Artemeva and Fox (2010) (and later, by Artemeva, Fox, and myself) was granted in 2007 and renewed annually. Permission to reproduce participants' likeness was not obtained for all IPs in that study; therefore, in some cases, facial features have been obscured in images and/or screen grabs or line drawings have been used in lieu of photographic images. In all cases pseudonyms have been used to protect participants' confidentiality. Informed Consent has been obtained from all participants. See Appendix C for documents pertaining to ethics approval.

5.3 Participants

The study includes two groups of participants, undergraduate students and university mathematics instructors. Phase 1 involves student participants (SRs) and instructor participants (IPs), and Phase 2 involves IPs exclusively. In Phase 1, inclusion criteria for SRs required that participants be undergraduate students majoring in engineering at an English-speaking university, having completed at least one core university mathematics course as part of their degree. Inclusion criteria for IPs required that instructors had taught mathematics courses to undergraduate students in English in English-speaking universities in Country A, Country B, or Country C. Although for all the IPs language of instruction was English at the time of the study, the majority of them spoke first languages other than English. The majority of *experienced* IPs were award-winning instructors.

5.3.1 Phase 1 participants

As noted above, Phase 1 of the study involved two groups of participants: SRs and IPs. The SR sample consisted of 12 upper-year and 44 first- and second-year undergraduate engineering students at a mid-size university in Country A. The student survey was piloted on a purposive sample of convenience of the 12 upper-year undergraduate engineering students who had taken numerous university mathematics courses in partial completion of their degrees, all of whom responded to the student survey. The other 44 SRs constituted a purposive sample of first- and second-year undergraduate engineering students who had been enrolled in and attended first-year core mathematics courses within a year of completing the survey. At the time of the study, this portion of the SRs were enrolled in a first-year core mathematics course for engineering majors. All SRs responded to the student survey.

The IP purposive sample of convenience included six mathematics instructors (four male and two female) employed at a mid-size university in Country A. The IPs' teaching experiences ranged from 10 to 40 years (see Table 1).

Table 1. Instructor participant profiles (Phase 1).

Instructor participant	Teaching position/	Years of teaching experience	Noted teaching awards at time of study	Languages spoken	Gender identity
(IP1)	Associate professor	20	Yes	English	Male
(IP2)	Professor	40+	Yes	Italian (L1), French, Spanish, English	Male
(IP3)	Instructor	10	No	Spanish (L1), Italian, French, English	Male
(IP4)	Instructor	14	Yes	Farsi (L1), English	Female
(IP5)	Associate professor	20	No	Russian (L1), Hebrew, English	Female
(IP6)	Professor (retired)	10	Yes	English	Male

5.3.2 Phase 2 participants

Phase 2 of the study involved two groups of IPs: Group A, university mathematics instructors whom I had personally contacted and requested that they participate in the study, and Group B, university mathematics instructors who had participated in the large-scale international study of university mathematics lecturing, conducted by Artemeva and Fox (2010) and who matched my criteria for inclusion. Group A consisted of seven mathematics instructors (five male and two female). At the time of the data collection, one IP was a professor, one was a retired professor, three were associate professors, one was an instructor, and one was a senior lecturer. Five of the IPs in Group A were employed at a mid-size university in Country A (also participants in Phase 1), and two were employed at a university in Country B.

Group B included six IPs (three male and three female). At the time the data were collected, two of the IPs were professors, three were post-doctoral fellows (post-docs), and one was a teaching assistant (TA). At the time, two of the IPs were employed at universities in Country A and five were employed at a major university in Country C. Their teaching experience ranged from 7 to 30 years (see Table 2).

Table 2. Instructor participant profiles (Phase 2).

Group	Instructor participant	Teaching position	Years of teaching experience	Noted teaching awards at time of study	Languages spoken	Gender identity	Country
A	(IP1)	Associate professor	20	Yes	English	Male	Country A
	(IP2)	Professor	40+	Yes	Italian (L1), French, Spanish, English	Male	Country A
	(IP4)	Instructor	14	Yes	Farsi (L1), English	Female	Country A
	(IP5)	Associate professor	20	No	Russian (L1), Hebrew, English	Female	Country A
	(IP6)	Professor (retired)	10	Yes	English	Male	Country A
	(IP7)	Associate professor	30	No	English	Male	Country B
	(IP8)	Senior lecturer	10	No	English	Male	Country B
B	(IP9)	Professor	Very experienced	Yes	English	Male	Country C
	(IP10)	Professor	Very experienced	Yes	English	Female	Country C
	(IP11)	Post-doc	Experienced teacher, novice mathematics lecturer	Yes	English (L1), Chinese	Female	Country C
	(IP12)	Post-doc	Novice	No	Russian (L1), English	Male	Country C
	(IP13)	TA (5^{th} year PhD)	Novice (7 years teaching)	No	English/French	Male	Country A
	(IP14)	Post-doc	Novice (approximately 8 years teaching)	No	Italian (L1), English	Female	Country C

5.4 Research Sites

As mentioned (Chapter 4, Section 4.5) the study was conducted on the campuses of universities located in three countries with English as an official language (Country A, Country B, and Country C).

5.4.1 Phase 1 research sites

Student surveys. The survey (Appendix A) was piloted to upper-year engineering SRs in a student study space in the engineering department of a mid-size university in Country A. Following the pilot, the surveys were administered to first-and second-year SRs in a lecture hall of the same university during an interim period of a core introductory mathematics course.

Instructor interviews. The two-part interviews were conducted at universities in Country A and Country B. They consisted of a written part, a questionnaire administered online to which IPs provided written responses, followed by a one-on-one semi-structured oral interview. The oral interviews were audio-recorded, transcribed, and analysed (see Appendix B for interview materials).

5.4.2 Phase 2 research sites

Video recordings (Group A) and follow-up interviews. The video recordings and semi-structured follow-up interviews were collected at two universities located in Country A and Country B. Six lectures were recorded at a university in Country A[19] and two were recorded at the university in Country B; that is, in total, eight lectures were collected. The follow-up interviews were conducted within a week of the recordings.

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[19] One IP gave two lectures, one using chalk and chalkboard and the other, using a newer form of teaching technology.

Video recordings (Group B). Of the lectures originally collected by Artemeva and Fox (2010), four were recorded at universities located in Country A and two at universities located in Country C.

5.5 Data Collection

Multiple types of data were collected to respond to the research questions. In Phase 1, quantitative data (SR responses to survey questions that used a Likert scale) and qualitative data (SR responses to open-ended questions and semi-structured interviews with IPs) were collected. In Phase 2, qualitative data were collected (video recordings of IPs teaching university mathematics lectures, observational notes, follow-up semi-structured interviews with IPs). The methods used to collect these data are described in the following subsections.

5.5.1 Phase 1 data collection

In order to respond to the first research question (*What constitutes student engagement in the chalk talk context? How can it be defined?*), Phase 1 involved the collection of quantitative and qualitative data using a survey instrument administered to SRs (see Appendix A) and qualitative data from two-part semi-structured interviews with IPs (instructor interviews) (see Appendix B).

Survey instrument. To determine what students find engaging in university mathematics instruction, I developed a survey instrument (see Appendix A) as a tool for measuring students' attitudes towards certain teaching strategies and instructor traits. In this dissertation, I refer to aspects of teaching (e.g., teaching practices, classroom behaviour, ways of interacting with students, personality traits, etc.) that have been associated with student engagement as *engagement constructs*. In order to develop a set of survey questions, a preliminary inventory of engagement constructs (see Figure 4) was established by drawing on studies of university mathematics lecturing (e.g., Artemeva & Fox, 2011; Fox & Artemeva, 2012), student engagement in STEM lectures (Gasiewski et al., 2012), and my previous field observations (e.g., Fogarty-Bourget, 2013). The inventory was also informed by Hyland (2001, 2005) to ensure the definition of engagement that I adapted from Hyland's work on engagement in written genres was an applicable starting point to begin development of a context-specific definition of student engagement.

Sources	Engagement definition (Hyland, 2005)	STEM literature (e.g., Artemeva & Fox, 2010; Gasiewski, et al., 2012)	Personal observations (e.g., Fogarty-Bourget, 2013)
Items	- Pronouns - Questions - Personal asides - Appeal to shared knowledge - Directives - Acknowledge as discourse participants - Acknowledge uncertainties - Pulling along - Focusing attn. - Recognizing presence - Guiding them to interpretations	- Interaction/collaboration o Group work o Clickers o Web-based pedagogy o Class discussion - Enthusiasm - Attitude - Knowledge base - Ability to explain content clearly - Excited - Passionate - Feel comfortable asking Qs o Profs encourage Qs ▪ Participation ▪ Supportive environments - Friendly - Playful - Humour - "open"	- Speed of delivery - Pitch and tempo - Humour - Scanning - Turned to class - Silence o Discursive (wait time) o Gestural - Clarity o Discursive o Writing on board - Rich language - Real-world examples - Empathy/putting self in students' shoes - Involving not telling

Figure 4. Screenshot of the preliminary inventory used to develop the survey instrument.

The 12 upper-year SRs to whom the survey was administered as a pilot (see Section 5.3.1) were asked to complete the survey while making note of any observations or points for clarification. After completing the survey, the SRs participated in informal follow-up interviews, in which the SRs were given the opportunity to discuss the survey and their responses. Based on the outcomes of the pilot, minor revisions to the wording and layout of the survey were implemented.

After minor revisions, the survey was administered to 44 first- and second-year undergraduate SRs (see Section 5.3.1). The instrument was used to collect demographic information (Section A) (see Figure 5 for an excerpt from Section A) as well as quantitative and qualitative data.

Section A: Demographic information

Age: ______________________

Gender: ___________________

First language: _______________

Language spoken at home: ______

Additional language(s): ________

____

Have you been schooled in languages other than English? Yes / No

If yes, please list the language(s) and the level of schooling: _______________

Figure 5. An excerpt from Section A of the student survey used to collect demographic information from respondents.

Quantitative data were collected from 34 questions in which SRs were asked to rank a series of engagement constructs on a Likert scale (Section B, Questions 1-34) (see Figure 6 for an excerpt from Section B).

Section B: In your opinion, a good mathematics lecturer:

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly Disagree
1) Speaks clearly	1	2	3	4	5
2) Checks to make sure students grasp the material	1	2	3	4	5
3) Asks questions	1	2	3	4	5

Figure 6. An excerpt from Section B of the student survey in which respondents were asked to evaluate a series of engagement constructs using a Likert scale.

Qualitative data were collected from written responses to two open-ended questions (Section C, Questions 1-2) (see Figure 7 for an excerpt from Section C).

Section C: Please answer the following questions:

1. If you have had an experience with a "very good" mathematics lecturer, what kind of things did they do that you *liked*?

2. If you have had an experience with a mathematics lecturer that was "not so good", what kind of things did they do that you *did not like*?

Figure 7. An excerpt from Section C of the student survey used to collect qualitative data with two open-ended questions.

The two open-ended questions were developed in order to probe student attitudes regarding teaching strategies and instructor traits that may not have been accounted for in the questions that used a Likert scale and to gain more in-depth insight into engagement from the student perspective. It is important to note that the wording of the survey did not include the term “engagement” in order to avoid any misinterpretation of the complex concept (Saris & Gallhofer, 2014). Instead, the questions were phrased in terms of quality of instruction (i.e., “very good”, “like” vs “did not like”). As will be discussed in the next section (Section 5.5.1) and chapters that follow, triangulation methods were used to ensure that the qualitative survey data, used to inform Phase 2, were related to student engagement and not merely the aspects of teaching that SRs found favourable.

Instructor interviews. Phase 1 included two-part semi-structured interviews with the IPs which had been designed to provide information about how instructors understand engagement in chalk talk contexts. For the first part of the instructor interviews, the IPs were asked to complete an adapted version of the survey instrument via email (see Appendix B). Adaption of the survey included minor adjustments to the questions pertaining to demographic information and in the wording of the open-ended questions. The IPs’ responses to the survey questions were used to help structure the second part of the interviews (oral interviews conducted face-to-face) and collect qualitative data from the IPs’ written responses to the open-ended questions (Appendix B, Section C of the adapted survey). During the oral component of the interviews, the IPs were asked a series of questions pertaining to their teaching practices, interactions with students, and understanding of engagement (see Appendix B for a sample interview guide). When appropriate, the IPs were asked to elaborate on their responses to certain parts of the adapted survey. The interviews spanned approximately 60-90 minutes and were audio-recorded with IPs’ permission.

The IPs’ written responses were typed up and compiled into a text document. Responses to the interview questions were transcribed on-site in the form of shorthand notes and the recordings were later auto-transcribed using *Transcriptions* (Klostermann, 2019), an online application designed for the transcription of interview data. In addition, I selectively transcribed parts of the recordings, namely, particularly rich, relevant, or insightful responses to interview questions. I compiled these data into themed text documents of "mixed selective transcripts" (Artemeva, 2006, p. 114) which combined some word-for-word transcription and some partial transcription (typed shorthand notes, field notes, and chunks of auto-transcribed text). These mixed selective transcripts contained sufficient detail to respond to my research questions (see Appendix D for a sample of the mixed selective transcripts).

5.5.2 Phase 2 data collection

Phase 2 involved the collection of qualitative data in the form of video (and audio) recordings of undergraduate university mathematics lectures, semi-structured follow-up interviews (post-recording), and field notes. These data were used to respond to the second research question (*What aspects of the chalk talk classroom context affect student engagement? What facilitates student engagement in this context? What makes student engagement difficult?*) and the third research question (*What strategies do university mathematics instructors use to help realize student engagement in chalk talk lectures?*).

Video and audio recordings. As mentioned in Section 5.2, two corpora of video recordings of undergraduate mathematics lectures were combined to establish the corpus of video data. The first group of recordings (Group A) was collected by me. They included lectures of seven IPs (five working in Country A and two working in Country B at the time of recording) and were recorded using high-resolution video cameras and external microphones. The IPs were recorded teaching one lecture each with the exception of IP2 who was recorded teaching two separate lectures. The collection includes eight lectures ranging from 60 to 180 minutes in length. The IPs were not given any special instructions prior to recording and were recorded delivering scheduled lectures to students as they would under otherwise regular circumstances. The IPs did not report making any special adjustments to their teaching for the recordings with the exception of IP2 (see footnote 18). At the time of recording, IP2 was teaching a condensed summer course which he delivered using a document camera projector (DCP), however, for the purpose of the study, he agreed to teach one of the lectures using chalk which he was accustomed to using and used in all other courses that he taught. Throughout the recordings, the cameras were trained on the IPs at all times. The audio data that were collected using the external microphones include students' anonymous spoken interactions with the IPs. These data combined with observational notes of student-instructor interactions that occurred during recording were used to inform my analysis.

As mentioned, the second group of recordings (Group B) was originally collected by Artemeva and Fox (2010) between 2007 and 2008 (Country A) and 2010 (Country B). From their corpus, seven recordings fit my inclusion criteria, that is, the IPs were instructors who had taught mathematics courses to undergraduate students in English in English-speaking universities in Country A, Country B, or Country C. The recordings contained lectures taught by six IPs who were in either Country A or Country C at the time of recording. All IPs from this group were recorded teaching one lecture each with the exception of IP9 who was recorded teaching two separate lectures (both recordings fit the inclusion criteria).

The two collections combined made up a corpus of 15 video recorded mathematics lectures (total of 19 hours 12 minutes, see Table 3) taught in English to undergraduate students majoring in Science, Technology, Mathematics, or Engineering programs. Of the recorded lectures, 13 were part of first- and second-year mathematics courses and two were part of upper-year (third- and fourth-year) mathematics courses. The lectures were delivered using a variety of teaching mediums including chalk, whiteboard, whiteboard paired with statistics software, paper and pen paired with DCPs, PowerPoint (PPT) slides, and pen-enabled tablets (penTPCs) (see Table 3 for descriptions of the video data contained in the corpus).

Table 3. Descriptions of the video data.

Group	Instructor participant (IP)	Lecture(s)	Delivery method	Duration	Recording details	Location
A	(IP1)	4^{th} year Dynamical Systems	Chalk and chalkboard	1hr 18min	Recorded by researcher	Country A
	(IP2)	1^{st} year Calculus for Engineering or Physics	Chalk and chalkboard	2hr 30min	Recorded by camera operator, research present	Country A
			DCP	2hr 40min		
	(IP4)	1^{st} year Differential Equations and Infinite Series for Engineering or Physics	DCP	1hr 10min	Recorded by researcher	Country A
	(IP5)	3^{rd} year Linear Algebra	PowerPoint slides with chalk and chalkboard	1hr 3min	Recorded by camera operator, research present	Country A
	(IP6)	Exam review for 1^{st} year Differential Equations and Infinite Series for Engineering or Physics	Chalk and chalkboard	2hr 29min	Recorded by researcher	Country A
	(IP7)	1^{st} year Core Statistics	Whiteboard paired with statistics software	44min	Recorded by researcher	Country B
	(IP8)	4^{th} year System Identification and Adaptive Control for Electrical Engineering	Microsoft tablet and projector screen	1hr 40min	Recorded by researcher	Country B
B	(IP9)	2^{nd} year Honours Calculus	Chalk and chalkboard	45min 53min	Originally collected by Artemeva and Fox (2010)	Country C
	(IP10)	3^{rd} year Probability and Statistics for Civil and Environmental Engineers	Whiteboard	46min		Country C
	(IP11)	2^{nd} year Computational and Applied Mathematics	Whiteboard paired with statistics software	50min		Country C
	(IP12)	1^{st} year Core Mathematics for Engineers	Chalk and chalkboard	44min		Country C
	(IP13)	2^{nd} year Mathematics Problem-solving Session Tutorial	Chalk and chalkboard	52min		Country A
	(IP14)	2^{nd} year Core Mathematics for Entry-level STEM	Chalk and chalkboard	48min		Country C
Totals	13 IPs	11 undergraduate mathematics courses	8 chalk 1 chalk + PPT 2 DCP 1 penTPC 1 PPT 1 whiteboard 2 whiteboard + statistics software	15 lectures 19hrs 12 minutes	8 lectures collected by Researcher 7 lectures originally collected by Artemeva & Fox (2010)	3 countries

Observations and field notes. As mentioned above, throughout the data collection process, I kept detailed field notes in order to record observations made during my interactions with IPs and while observing the IPs interacting with their students. When resources were available, Group A recordings were collected with the assistance of a camera operator so that I was able to focus my attention on observing the lectures and recording field notes. I included in the notes sketches of classroom layouts and the number of students seated in the classrooms and their seating arrangements, and recorded relevant oral exchanges that occurred between students and the instructor, notable points in the lectures, as well as contextual elements such as the atmosphere of the classroom (see Appendix E for samples of the field notes). The field notes were used to inform the multimodal analysis of the video data as well as the post-recording follow-up interviews.

Follow-up interviews. The IPs were interviewed within a week of having their teaching recorded. The interviews were informed by my observations and field notes, and semi-structured with questions pertaining to their teaching and classroom interactions with students. In addition to these questions, IPs were shown excerpts from the video recordings of their own teaching and asked to provide feedback on their performance. The follow-up interviews provided an opportunity to receive contributions from the IPs regarding any aspects of the data that required further insight. The interviews were approximately 60 minutes in length and were audio-recorded.

5.6 Methods of Data Analysis

The study used a combined methodological framework involving statistical analysis of quantitative data and Qualitative Multimodal Thematic Analysis (QMTA)

(Fogarty-Bourget, 2013) of qualitative data. This section presents the statistical methods employed in the analysis of the quantitative data, followed by a discussion of QMTA including an overview of the conceptual underpinnings of the approach, namely multimodal (inter)action analysis (Norris, 2004, 2011) and constructivist grounded theory (Charmaz, 2006, 2012), and description of the general procedure used to conduct QMTA.

5.6.1 Statistical methods

Statistical analysis of quantitative data collected from SRs responses to the questions that used a Likert scale (Section B of the survey, Appendix A) was conducted using SPSS v.22 (IBM Corp., 2013). Cronbach's alpha was calculated to test the reliability of the scale. Cronbach's alpha is the most widely reported reliability statistic. It is used as a measure of inter-item correlation expressing the internal consistency reliability of a survey instrument (i.e., to test whether different parts of a test or different items in a test designed to measure the same phenomenon actually do so) (Vogt, 2007, pp. 114-115). Cronbach's alpha is determined by calculating the split-half reliability, assessed by splitting the items from the instrument in half, and then correlating the scores on each half separately to get an assessment of the consistency of the questions, of all possible measures and then taking an average of all the coefficients. Cronbach's alpha ranges from 0 (when the items are completely inconsistent) and 1.0 (when the items are perfectly correlated) with an alpha of .70 or higher is considered satisfactory for this type of measure (Vogt, 2007, p. 115). Descriptive statistics of the responses to the questions that used a Likert scale (ranked on a scale of 1 *Strongly Agree* to 5 *Strongly disagree*) were used to measure agreement amongst SRs regarding the importance of the engagement constructs being tested.

5.6.2 Qualitative multimodal thematic analysis (QMTA)

QMTA, which I started developing in my Master's research (2013), is a method of coding developed for analysing rich, text-based or multimodal data, including video and audio recordings paired with transcripts. The approach has its roots in multimodal (inter)action analysis (MIA) (Norris, 2004, 2011) and constructivist grounded theory (Charmaz, 2006, 2012), and works in concert with these two approaches.

Multimodal (inter)action analysis (MIA). As discussed in Chapter 2 (Section 2.4), MIA is a methodological approach that enables the multimodal analysis of social interaction. MIA takes the mediated action as the unit of analysis, which can be “delineated” into *lower-level* and *higher-level actions* (Norris, 2015, p. 44). A *lower-level-mediated action* is a mode’s smallest meaningful unit and higher-level actions are “made up of a multitude of chains of lower-level actions” (Norris & Makboon, 2015, p. 44). An example of a lower-level action is a single gesture, or eye-movement, whereas an example of a higher-level action would be a greeting, written equation, or whole mathematics lecture. As Norris and Makboon (2015) suggest, higher-level actions can be defined on different scales, and, although lower-level actions can be easier to define, both can be distinguished according to their points of beginning and end (p. 44). It is important to note that what qualifies as a “meaningful unit” depends largely on the researcher and research objectives of the investigation, thus, like higher-level actions, lower-level actions may also be defined on different scales depending on the phenomenon of interest (see Fogarty-Bourget, Pirini, & Artemeva, n.d.). In addition to lower-level and higher-level actions, MIA also identifies *frozen* actions (Norris, 2004, 2011; Norris & Makboon, 2015) which are embedded in objects and the environment such as clothing, furniture and room décor. MIA has most commonly been used to investigate social interaction through the collection and analysis of multimodal data including video recordings (e.g., Norris, 2004; Pirini, 2014), Skype recordings (Norris, 2016), digital reproductions of advertisements (White, 2017), and photographs (Norris & Makboon, 2015).

Constructivist grounded theory (Charmaz, 2006), like MIA, requires the collection of rich data which are "detailed, focused, and full" (p. 14). The method of data collection, Charmaz suggests, ought to be shaped by the research problem which may point to one, or several combined or sequential methods. Data must then be *coded* (categorizing segments of data with a short name that simultaneously summarises and accounts for each piece of data [2006, p. 43]) beginning with initial coding in which fragments are studied word by word, line by line, or incident by incident. Initial coding is followed by focused coding, a process in which the most significant or frequent initial codes are tested against extensive data. This phase requires that the researcher make decisions about which of the initial codes make the most sense with which to categorize the data. Theoretical coding (Glaser, 1978) follows focused coding in order to specify possible relationships between categories developed in the focused coding stage. Constructivist grounded theory sees memo-writing as constituting a crucial method which prompts the researcher to analyse data and codes early in the research process, and helps to articulate comparisons and form conceptual connections. Finally, theoretical sampling is conducted; this is the process in which pertinent data are collected in order to develop the properties of the categories until no new properties emerge (*saturation*) so that they can be sorted and integrated into a theoretical statement.

QMTA adopts a similar process of continual coding and categorization to constructivist grounded theory, however, because it draws on MIA, it is better suited for the analysis of multimodal data, such as video recordings and photographs, in addition to textual data collected from interviews, focus groups, and written discourse. QMTA complements a pragmatic worldview because, like constructivist grounded theory, QMTA can be used as an inductive approach to generate theory. Unlike constructivist grounded theory, however, QMTA can also be used top-down, or deductively, to test theories as is more typical of quantitative research.

In this study, QMTA was used in the qualitative analysis of textual data collected from the written responses to open-ended survey questions, as well as interview, and video data. The procedure for conducting QMTA varies slightly depending on the research question being investigated and type of data being analysed, however, the process is generally carried out as follows:

1) Data are prepared for coding (i.e., transcribed, time-stamped (where appropriate), and uploaded into a qualitative coding program[20]).
2) Descriptive coding is applied to the smallest meaningful units of data as determined by the level of inquiry (e.g., gesture phases, topic changes, speaker turns, etc.).
3) Descriptive codes are grouped together (when appropriate) into categories.

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[20] QMTA can be conducted manually (i.e., without the use of coding software), however, this research uses software-facilitated QMTA which includes the use of qualitative coding and/or transcription software (e.g., NVivo 11 [QSR International, 2017], ELAN [Max Planck Institute for Psycholinguistics, 2019]).

4) Categories are then grouped together into overarching themes.

The coding process is accompanied by memo-writing and is continued until saturation (Glaser & Strauss, 1967) is achieved. The bottom-up application and grouping of descriptive codes forms the basis of a coding tree of recurrent themes. The developed coding tree can then be applied when relevant to other data in a top-down fashion.

Although QMTA is a qualitative approach to analysis, the software-assisted coding process facilitates the “quantitization” (Plano Clark & Creswell, 2008, p. 281) of qualitative results. Dornyei (2007) describes the technique of “quantitizing” as involving the conversion of qualitative data into numerical codes that can be further processed statistically, a process used by qualitative researchers who wish to produce numerical tabulations of certain aspects of their data in order to achieve a thorough description of results (pp. 269-270) (see also Plano Clark & Creswell, 2008, p. 281; Kitchenham, 2012). Using software designed for qualitative coding in the analysis of multimodal data not only provides analysts with a tangible record of their analytical process, but also enables researchers to examine their data from numerous perspectives. For instance, by applying descriptive codes to all lower-level actions (e.g., gestures, shifts in gaze directionality, movements of the head, and body) produced by an IP in a video recorded lecture using qualitative coding software, an analyst can use the software to run queries (i.e., ask questions) about when and how frequently the actions occur and how they relate to other actions that have been coded. Information regarding the frequency and patterning of the coded actions can then be tabulated in the form of numerical results (i.e., “quantitized”), used to visualize the data in different ways (e.g., frequency tables, word clouds, comparison diagrams, etc.,), and/or for comparative studies of different individuals or contexts. While not generalizable, the quantitization of qualitative data can provide insight beyond the typical scope of qualitative inquiry. In this study, the quantitization of descriptive coding is used to help interpret large amounts of rich textual and video data.

Analysis of textual data. As described previously (Subsection 5.5.1), the survey instrument included two open-ended questions (see Section C, Appendix A). The questions asked SRs to describe their personal experiences with “very good” and/or “not so good” mathematics instructors and any corresponding teaching strategies these instructors may have used. A bottom-up approach to QMTA was conducted facilitated by NVivo 10 (QSR International, 2012). The analysis of SRs’ responses to open-ended questions was conducted by transcribing the written responses into a text document, then uploading the text document into NVivo 10. Descriptive coding was applied to fragments of text at the topic level (see Saldaña, 2009) identified by key words or short phrases. Next, descriptive codes were grouped together into categories, and categories into overarching themes (cf. Charmaz 2006) which was used to develop a coding tree of descriptive themes. The process was continued until all the transcribed text was coded and no new insights were apparent (see Appendix F for a screenshot of NVivo coding of textual data).

Analysis of interview data. The data collected from the instructor interviews consisted of written responses to the adapted survey, audio recordings of the interviews, and real-time transcriptions in the form of shorthand notes. These data were compiled into mixed selective transcripts (see Section 5.5.1, also Appendix D). The mixed selective transcripts were uploaded to NVivo 11 and the data were analysed in the same way as the textual data collected from the SR responses to the open-ended questions (see Appendix F for sample of textual data and coding tree).

Analysis of video data. QMTA of the video data was informed by the results of Phase 1. The coding tree developed in the bottom-up analysis of the textual and interview data acted as a “start list”, or a list of “possible categories that may be relevant to coding” (Geisler, 2004, p. 60) and the inventory of engagement constructs (see Section 5.5.1, Figure 4) was used to identify strategies used by the IPs to engage students during the video recorded lectures. Thus, QMTA was conducted in a top-down fashion, while still remaining open to the discovery of new, conceptually independent features not yet included in the coding scheme.

Preliminary analysis of the video data was conducted as follows: (1) The corpus of video recordings was uploaded into ELAN[21] [Max Planck Institute for Psycholinguistics, 2017] which works well for the transcription and analysis of large video files (e.g., Max Planck Institute for Psycholinguistics, 2019; The University of Melbourne, 2019); (2) Excerpts in which instructors were working to engage students were identified and demarcated; (3) Descriptive coding was applied to relevant higher- and lower-level actions; and, when more fine-grained coding was required, (4) Demarcated segments of video were uploaded into NVivo 11 (QSR International, 2017) which facilitates the application and visualization of particularly dense descriptive coding (see Figure 8 for an example of descriptive coding using NVivo 11).

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[21] ELAN is available for free download at http://tla.mpi.nl/tools/tla-tools/elan/.

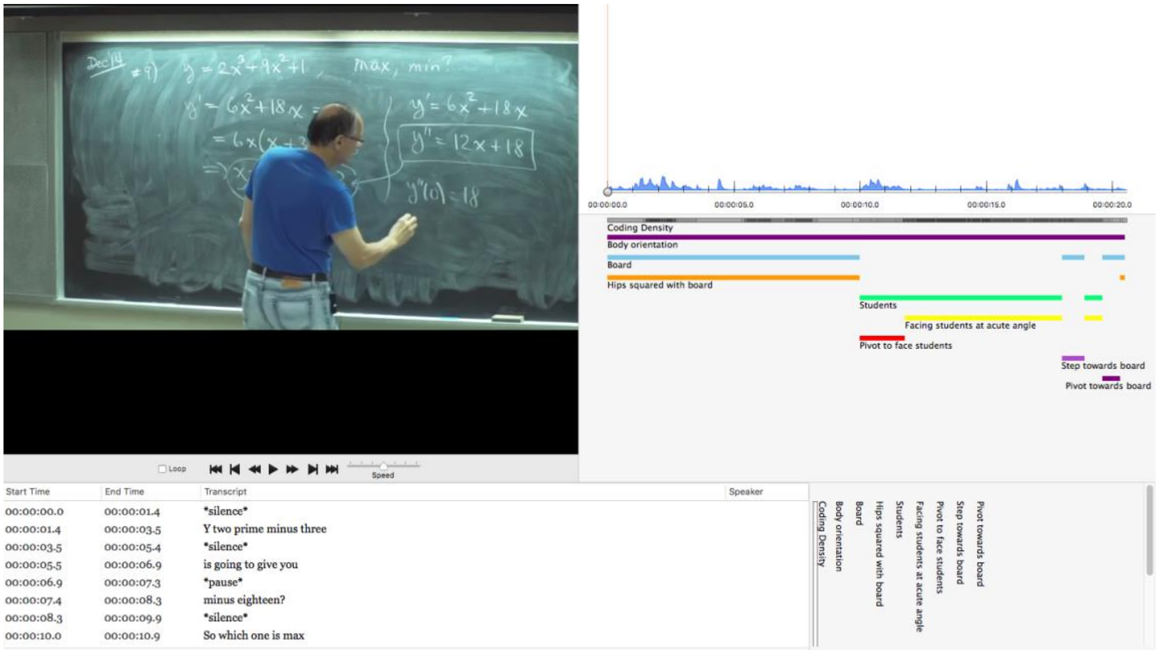

Figure 8. Screenshot of software facilitated descriptive coding of body orientation (NVivo 11).

Further analysis of the video data varied depending on the phenomenon of interest being investigated, as well, the units of analysis used for coding was dependent on the communicative mode being analysed. Particular analytical procedures used to respond to particular research questions or lines of inquiry are presented in the following chapters (pp. 168-170, 181-183, 188-189, 217-218).

5.6.3 Triangulation methods

Triangulation is a validity procedure wherein researchers use multiple sources of information to verify the interpretations made from the data (Creswell & Miller, 2000). Approaches to triangulation may involve researchers drawing on multiple and different methods, sources of data, theories, and investigators to corroborate their findings (Artemeva, 2006; Creswell & Miller, 2000; Denzin & Lincoln, 2000). I used multiple strategies to triangulate my findings including collection of multiple types of data from multiple study participants (data triangulation), inclusion of participant feedback (member checking), and collaboration with additional researchers (intercoder reliability). The collection of field notes during classroom observations acted as a means of data triangulation to verify my interpretations of the interactions captured in the video recordings. The post-recording interviews provided an opportunity for the instructor participants to view the raw data and verify the accuracy of my resulting interpretations. In this way the post-recording interviews acted as member checks wherein the participants could confirm that my conclusions were realistic, and in turn I was able to incorporate the participants comments and feedback into the final narrative (see Creswell & Miller, 2000) to achieve an accurate representation. Additional member checks were conducted as needed to ensure the participants approved of the final narrative account.

To achieve intercoder reliability, an experienced researcher was enlisted to code segments of data using my final coding scheme. The researcher was debriefed as to the nature of the study, the method of qualitative multimodal coding, and the units of analysis used for coding the relevant modes. The researcher then coded a segment of data independently and afterwards the coding was compared with my own. Cohen's kappa, one of the popular types of agreement estimates of interrater reliability (Stemler & Tsai, 2008, p. 32) was used as a measure of inter-rater agreement. Cohen's kappa is used as a measure of agreement between raters for categorical scales when there are two raters independently assessing the same observations (i.e., the same phenomenon) using the same scale (Laerd Statistics, 2018), thus, Cohen's kappa is an appropriate measure for this rater comparison. Cohen's kappa can range from -1 (agreement less often than chance would predict) to +1 (perfect agreement) with a value of 0 indicating a level of agreement predicted by chance (Stemler & Tsai, 2008, p. 34). According to Stemler and Tsai (2008), a kappa value of 0.50 is considered acceptable interrater reliability (p. 47). After the initial round of coding, Cohen's kappa was calculated and a kappa of .88 was reached which indicates substantial agreement meaning that the coding was consistently applied by each analyst. Afterwards, the results were reviewed and cases in which the researcher's misuse of terminology were rectified. Following the review session, Cohen's kappa was recalculated and a value of .90 was achieved indicating near perfect agreement.

As mentioned in the introduction to this chapter, this study was conducted from a pragmatic perspective wherein both objective and subjective forms of knowledge and knowledge seeking are valued. As such, I recognize the existence of researcher bias as well as the interpretive nature of qualitative research and thus the need to include checks to ensure rigour and trustworthiness (see Lincoln & Guba, 1985; McAlister et al., 2017). The use of these various triangulation strategies verifies that the interpretations made in this dissertation are trustworthy and credible.

The findings of this research are presented and discussed in the next four chapters (Chapters 6-9). In Chapter 6, the results of the student surveys and analysis of the IPs written responses to the open-ended questions of the pre-interview questionnaires are presented. In Chapters 7, 8, and 9, I present and discuss the findings of Phases 1 and 2 in light of the relevant research literature. In Chapter 7, I discuss what constitutes student engagement in the chalk talk lecture context and present the context-specific definition that was the result of my research. As well in Chapter 7, I identify and describe the aspects of the learning environment and classroom climate that are influential to student engagement in this context. In Chapter 8, I discuss the use of teaching technologies in chalk talk lecturing specifically in reference to how such technologies may shape student-instructor interaction. Finally, Chapter 9 presents and discusses the strategies instructors of university mathematics use to help realize student engagement in the chalk talk classroom.

Chapter 6: Constructs of Student Engagement in Chalk Talk Lectures

The findings of Phase 1 help us understand the construct of student engagement in the university mathematics (chalk talk) teaching context as discursively constructed by SRs and IPs. This chapter presents the results of the survey data. The first section reports the results of the student survey. The second section presents the findings of the qualitative analysis of the IPs' written responses to the open-ended questions of the pre-interview questionnaire.

6.1 Student Survey Results

This section presents the results of the quantitative component of the student surveys, that is, SRs responses to the Likert items (Appendix A). These are followed by the findings of the thematic analysis of the qualitative component, that is, SRs written responses to the open-ended questions (Appendix B). The section concludes with a brief summary of the outcomes of the survey.

As discussed in the previous chapter, analysis of the SRs' responses to the Likert items (Section B of the student survey, Appendix A) was facilitated by SPSS. Cronbach's alpha was used to test the reliability of the scale; the alpha for the scale was .84 which is a satisfactory level of accuracy for this type of measure. Descriptive statistics of the SRs' responses to the Likert items was conducted in order to measure agreement amongst the SRs regarding the importance of the engagement constructs included in the preliminary inventory (see Appendix G for descriptive statistics of responses to the Likert items). The following constructs, which were developed by drawing on studies of university mathematics lecturing (e.g., Artemeva & Fox, 2011), student engagement in STEM lectures (Gasiewski et al., 2012), and my previous field observations (e.g., Fogarty-Bourget, 2013), (ranked on a scale of 1 *Strongly Agree* to 5 *Strongly disagree*) scored the highest among the SRs as attributes of a "good" mathematics lecturer:

- *Is able to explain content clearly* (mean 1.29, SD .55)
- *Speaks clearly* (mean 1.34, SD .52)
- *Is approachable* (mean 1.34, SD .56)
- *Writes neatly and clearly on the chalkboard* (mean 1.4, SD .69)
- *Allows time to take notes* (mean 1.56, SD .62)
- *Organizes chalkboard notes in a way that is easy to follow* (mean 1.56, SD .72)
- *Checks to ensure students grasp the material* (mean 1.61, SD .76)
- *Is an expert in the field* (mean 1.72, SD .82)

The following constructs scored the lowest among SRs as attributes of a "good" mathematics lecturer:

- *Speaks quickly* (mean 3.93, SD .92)
- *Is focused mainly on the chalkboard* (mean 3.4, SD .89)
- *Promotes class discussion* (mean 2.95, SD 1.16)
- *Organizes group work and discussions* (mean 2.86, SD 1.13)
- *Does not stray from mathematical content* (mean 2.84, SD 1.03)
- *Describes the beauty of math* (mean 2.81, SD 1.14)
- *Moves around the room* (mean 2.77, SD 1.09)
- *Uses technology in the classroom* (mean 2.72, SD 1.01)

The two open-ended questions (Section C of the student survey) asked SRs to describe past experiences with "very good" and "not so good" mathematics instructors and associated teaching strategies and behaviours. Qualitative analysis of the written responses to the open-ended questions resulted in the emergence of these themes and categories:

Question: If you have had an experience with a "very good" mathematics lecturer, what kind of things did they do that you liked?

1. Employs a logical and inclusive lecturing style

- Presentation of material is clear, logical, and accessible
    - Speaks and writes clearly, notes are legible, well organized, and easy to follow
    - Breaks complex concepts down into steps and illustrates concepts with examples
- Lecturing is well-paced, and students are involved in the dialogue
    - Checks for understanding before moving on
    - Includes students in problem solving, asks questions
- Instructor is positive and passionate about the material and teaching
    - Appears to enjoy teaching and conversing with students
    - Shows genuine interest in and passion for subject matter

2. Demonstrates evidence of a rich knowledge base

- Instructor is regarded as knowledgeable
    - Explains complex concepts carefully and in simple terms
    - Answers any questions that students pose

- Explanations are accompanied by ample "concrete", diverse, or "real-world" examples

3. Portrays a student-focused "teaching persona"[22](cf. Artemeva and Fox, 2010)

- Instructor is attentive and in tune with students' needs and uncertainties
    - Ensures that students feel seen and heard
    - Checks regularly that students understand the material and can see the writing on the board (often referred to as "checking")
    - Prepares students well for exams and grades fairly
- Relationship with students is positive and care is shown for students' success
    - Appears friendly and approachable
    - Uses humour and/or storytelling in the classroom
    - Behaves in a way that is personal yet professional

Question: If you have had an experience with a mathematics lecturer that was "not so good", what kind of things did they do that you did not like?

1. Employs an inward, dispassionate lecturing style

- Presentation of material is unclear and/or difficult for students to follow
- Lecturing is dry, dull, and/or focused mainly on theory
- Explanations are insufficient, shallow, and/or presented too quickly

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[22] This theme is very similar to the concept of "teacher persona" described by Artemeva and Fox (2010) as "the character" teachers play as they teach, which can create a welcoming and inclusive atmosphere or range to a distanced rational- scientific atmosphere (p. 177).

2. Fails to demonstrate evidence of rich knowledge base

- Ignores or neglects student questions
- Appears to lack confidence, exclusively follows textbook, and/or makes frequent mistakes
- Provides insufficient examples and/or explanations

3. Portrays a detached, inaccessible teaching persona

- Appears inattentive, unfair, and/or inconsistent
- Adopts a negative stance towards students and teaching
- Overlooks students' individual needs and/or fails to account for student diversity

Descriptive statistics of responses to Likert items confirmed that SRs agreed that the majority of the engagement constructs included in Section B of the survey were important features of undergraduate mathematics instruction (overall mean 2.2, SD .57). Lending support to the quantitative analysis, many of the engagement constructs that the Likert items were designed to test were reiterated by the SRs in their written responses to the open-ended questions. Interestingly though, while engagement constructs such as *Uses humour in the classroom*, *Is Friendly*, and *Describes the beauty of Mathematics* did not score highly as qualities of a "good" mathematics lecturer, statements that "very good instructors" were "friendly", "fun", "passionate", "told jokes", and "enjoyed teaching" were frequent in the written responses. This may indicate that SRs associate these qualities with "very good" instructors but disagree on the extent to which they are necessary components of good lecturing. Although Section B of the survey appears to work effectively as a measure of the engagement constructs identified in current research literature and previous personal observation, the responses to open-ended questions were equally informative in that they uncovered several items (potential constructs) that had not been identified in the preliminary inventory. In addition, the written responses were useful for gaining insight into traits that SRs found *unfavourable*, some of which did not mirror traits that SRs did find favourable. For example, “lack of confidence” was cited as a trait of a “not so good” instructor, however, “confidence” was not cited as a trait of a “very good” instructor. This observation could suggest that understanding what *doesn’t* engage students may provide insight into qualities that do.

Overall, these findings indicate that the survey functions as a reliable instrument to measure student attitudes toward the selected engagement constructs. It is important to reiterate that, while the student survey focused primarily on attributes of “good” mathematics lecturers, the constructs that the instrument was designed to test had been identified as aspects involved in, or facilitatory to, engagement in relevant research literature on student engagement and in empirical research on university mathematics lecturing (see Chapters 3 and 4). Thus, it appears that those constructs which had the highest ratings amongst SRs as attributes and behaviours of “good” mathematics lecturers likely contribute to students’ engagement in chalk talk lectures. Furthermore, the constructs which were frequently cited in the written responses as qualities of “very good” mathematics lecturers but were rated lower in the responses to Likert items can also be considered verified as constructs of student engagement. Any additional attributes or behaviours identified by SRs in the written responses may not relate to engagement per se (i.e., items that are potential constructs) unless corroborated by IPs as strategies used to engage students.

6.2 Instructors' Written Responses to the Pre-interview Questionnaire

As mentioned in the previous chapter (Chapter 5), the instructor interviews included a written component and semi-structured oral component. The findings of the textual analysis of the IPs' written responses are presented in this section. In the written responses to the open-ended questions, the IPs described qualities of a "very good" mathematics lecturer as well as aspects of the practice that they felt could generally be improved upon. The qualities that the IPs attributed to a "very good" mathematics lecturer corresponded to three areas of teaching: teaching philosophy, delivery of the subject matter, and teacher persona (see Appendix H for complete list of categories involved in each overarching theme).

Teaching philosophy. The IPs described an approach to teaching in which the "very good" mathematics lecturers exemplify the professional practice of doing mathematics by making transparent (in speech and writing) their thinking process in real-time. In doing so, the "very good" mathematics instructors inspire the students by own example in part by conveying their admiration for the subject matter. This teaching philosophy also involves a recognition for the practice of teaching mathematics wherein the instructor maintains a commitment to teaching quality (see Figure 9).

Teaching Philosophy of the "Very Good" Mathematics Instructor

Exemplifies the professional mathematician

- Demonstrates the professional practice of doing mathematics
- Inspires students by example
- Makes transparent the thinking process of doing mathematics in real-time

Conveys admiration for subject matter

- Shares with students an excitement for learning new things
- Possesses a keen sense of the value of the subject matter and its current and future real-world applications beyond the classroom
- Recognizes that mathematics is a "living subject" and treats it as such

Shows a regard for the practice of teaching

- Maintains a commitment to teaching quality
- Places an importance on preparedness
- Remains adaptable and receptive to new teaching tools, technologies, and needs of students

Figure 9. Qualities that reflect the teaching philosophy of a "very good" mathematics instructor according to IPs.

Delivery of subject matter. In their written responses, the IPs conveyed the importance of delivering subject matter in a way that is clear, logical, and effective using a lecturing style that is interactive and mindful of students' needs. In addition to presenting the material in a way that is compelling, the IPs noted that it was important to help the students to make connections between the concepts at hand and the broader social sphere (i.e., in other areas of the discipline, industry, and/or professional realm) (see Figure 10).

Exceptional Delivery of the Subject Matter

Delivery is comprehensible and compelling. Instructor

- Presents material clearly and logically
- Communicates effectively
- Possesses the ability to explain material at the most elementary level
- Makes concepts attractive (e.g., chooses illuminating examples, uses colour)

Lectures are interactive. Instructor

- Promotes student involvement and participation
- Faces students while teaching, looks around the classroom, makes eye contact with students
- Checks in with students to ensure comprehension before moving on

Subject matter is extended beyond the immediate context. Instructor

- Helps the students make connections between mathematics on the blackboard and other areas of mathematics or STEM discipline(s) and/or professional industries
- Provides real-world examples

Figure 10. Qualities that reflect the style of delivery used by a “very good” mathematics instructor according to IPs.

Teaching Persona. Finally, the IPs described the teaching persona of a “very good” mathematics lecturer as demonstrating a passion for teaching and learning mathematics and a rich knowledge base. The qualities of this teaching persona include approachability, humility and patience. The “very good” mathematics lecturer is student-focused showing respect for students and concern for their success while remaining open and receptive to learning new things (see Figure 11).

The Passionate and Student-Centred Teaching persona

Instructor is passionate and knowledgeable

- Demonstrates passion for teaching and learning
- Possesses rich knowledgebase and real-world experience
- Inspires students and provides motivation
- Understands a variety of approaches to the subject matter

Students are valued and respected. Instructor

- Establishes a rapport and maintains connection with students
- Shows care for students' well-being and progress
- Remains sympathetic to the student experience
- Respects students and shows no preferential treatment
- Behaves is a way that is personal but professional

Instructor is receptive and "open"

- Appears approachable, accessible, and human
- Exercises humility and patience
- Remains open to learning new things and learning from students

Figure 11. Attributes of the teaching persona generated by a "very good" mathematics instructor according to IPs.

Areas of improvement. The aspects of mathematics lecturing that IPs identified as potential areas of improvement emerged as two overarching themes:

1) A mismatch of expectations: This theme involves behaviours that imply the instructor's expectations are incongruent with those of the students. These behaviours include:
    - Leaving gaps in explanations
    - Teaching "over students heads" and/or conveying omniscience
    - Overemphasizing methods or procedural math that may not be relatable to students outside the mathematics discipline
2) Low teacher-immediacy: This theme involves behaviours that can cause an instructor to appear disconnected from their students and/or teaching. These behaviours include:
    - Avoiding eye contact with students
    - Focusing on presenting material over listening to students
    - Lacking passion for the material and/or confidence in teaching skills
    - Feeling unprepared to explain content or present sufficient examples

The data collected from the IPs' written responses were comparable to the data collected from SRs' written responses regarding the attributes of "very good" mathematics lecturers and qualities and behaviours that are considered less favourable in the chalk talk teaching context. The findings presented in this chapter inform my understanding of what constitutes engagement in the university mathematics teaching context and contribute to the context-specific definition of student engagement presented in the next chapter (Chapter 7). Certain aspects identified by SRs and IPs in the written responses, such as personality traits that contribute to the teaching persona, for example, are important to recognize because while such aspects are not explicitly used to help realize student engagement, they impact the ways that students interact with instructors and the degree to which they are willing to do so (see Artemeva & Fox, 2010; Bergsten, 2012, Gasiewski et al., 2012) as further discussed in Chapter 7 (Section 7.3).

Chapter 7: Defining Student Engagement in the Chalk Talk Lecture

In this chapter, I draw on my analysis of the instructor interviews and relevant research literature to further my understanding of what constitutes student engagement in the chalk talk context. The chapter begins by describing student engagement as reported by the IPs of my study. I then present the newly developed, context-specific definition of student engagement that resulted from Phase 1 of the research. Lastly, the ways that instructors identify student engagement in chalk talk lectures are discussed and student behaviours that IPs cite as indicative of student engagement are presented.

7.1 Jointly Doing Mathematics: Students and Instructors Co-acting Engagement

A recurrent theme throughout the interviews was the understanding of engagement as a co-acted phenomenon wherein students and instructors co-construct the teaching of the lecture and learning of the subject matter. The IPs described engagement as a shared “response” to the process of teaching and learning, creating a scenario “in which the instructor and the class are almost as one” in a state of “symbiosis” (IP3). Engagement in a chalk talk context, according to the IPs, is a joint experience where instructors are drawing forth the learning, and students are involved as part of the process of discovery. IP3 articulated this sentiment during our interview:

> . . . we [the students and I] are like one in the teaching-learning process, where, I just started maybe before you [the student] and that's why I’m grabbing the chalk but I'm also learning, you know? . . . I'm also learning a lot from lectures. Not only from preparing them . . . but in the classroom, thanks to feedback, I also learn,

> because . . . stuff I would think very rigidly about, they [the students] come up with a fresh approach.

This excerpt is significant to the study of student engagement because it demonstrates what Chi and Wylie (2014) describe as the interactive mode of engagement (the highest level of learning according to the ICAP framework) which occurs only through joint dialogues (or dialoguing) resulting in mutual learning or generation of knowledge (p. 223). Chi and Wylie generally view students' engagement in mathematics lectures as active (listening and taking notes) or constructive (asking and answering questions and problem-solving). More traditional pedagogical perspectives have positioned students' engagement in chalk talk lectures as passive in nature wherein students simply listen and blindly copy notes (e.g., Bligh, 2000; Paoletti et al., 2018); however, as the findings of my study indicate, this is an inaccurate and likely ill-informed assessment (cf. Sfard, 2014).

Throughout the interviews, and as the quote from IP3 above suggests, there was little sense of a strict division of labour in regard to who was responsible for 'doing' engagement or 'being' engaged. Contrary to more traditional conceptualizations of student engagement as "something that teachers do to students", the IPs in my study saw themselves as facilitators of student engagement, which in their view *is* "something that students and teachers generate together" (McMahon & Portelli, 2004, p. 66). The IPs did not pose the students as passive receivers of the lectures wherein it was the instructors' responsibility to engage the students, nor did they allow the onus to fall solely on the students to be engaged (cf. Finn & Zimmer, 2012; Steinberg, 1996; Strong, Silver, &

Robinson, 1995). Instead, the IPs positioned students as active participants in the teaching-learning process (see Chavez & O'Donnell, 1998). This understanding of teaching and learning as an inherently social, co-constructed phenomenon corresponds to the sociocultural perspective and, in particular, notions of situated learning (e.g., Rogoff, 1990; Vygotsky, 1987) (see Section 2.3). The IPs described *making space* for the students to get involved in (co)creating the math, *leading* students in their "guesses" (IP2), and in turn, *allowing* students' contributions to feed forward the lecture and thus, the learning:

> "Students are involved, part of the process, drawing forth the learning, creating the math *with*[23] the instructor". (IP6; emphasis his)

> "You lead them to their guess. Let them get involved in the act of creation, cause that's the cool part, that's what it's all about". (IP2)

The practice of "drawing forth" the students' learning and guiding students toward correct interpretations reflects Hyland's (2005) definition of engagement and embodies the fundamental principles of Vygotsky's (1987) ZPD and Rogoff's (1990) guided participation). In the chalk talk lecture context, the instructors create opportunities for students' learning and provide scaffolding (Wood, Bruner, & Ross, 1976) by doing mathematics together with the students at a level that is slightly ahead of students' actual knowledge (Mason, 2000; Vygotsky, 1987; see also Sfard, 2014, on the "massive

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[23] Italicized text within participant quotes indicates direct speech is emphasized with vocal stress (see Transcription Notations, p. xi)

scaffolding" [p.202] of some university mathematics teaching). In this context, wherein tasks are developed specifically for learning, students' active participation is key (Rogoff, 1990). IP3 described this collaborative process as "narrowing the gap" between teacher and student:

> "Engagement is to narrow the division between lecturer and student; by encouraging participation that gap becomes less clear". (IP3)

IP6 also made clear the indispensable nature of students' participation in engagement which he defined in an interview as "Participation *and* involvement *and* attention". There was unanimous agreement throughout the interviews, that student engagement was comprised of students' focused attention, involvement (even if that manifested as "active listening" or some discernible "effort" to think of responses), and their active participation (these student behaviours are discussed further in section 7.2).

Based on the results of the student survey and findings of the analysis of the instructor interviews, and, in line with interactional notions of engagement as presented in relevant research literature (e.g., Biza, Jaworski, & Hemmi, 2014; Chavez & O' Donnell, 1998; Hyland, 2005; Pianta, Hamre, & Allen, 2012), I define student engagement in the chalk talk context as

> a state of sustained mutual activity wherein participants (i.e., the students and instructor), through a series of communicative exchanges, including instances of directed attention, involvement, and participation, cooperate towards accomplishing

> a shared task, which, in the context of the chalk talk lecture, is that of doing mathematics.

This definition captures the reciprocal, dialogic (cf. Bakhtin, 1986), and inherently interactive nature of engagement, and the co-acted, jointly-constructed nature of the chalk talk lecture as described by IPs in my study and elsewhere in the research literature (e.g., Artemeva & Fox, 2010, 2011; Fogarty-Bourget, 2013; Greiffenhagen, 2014; Speer, Smith, & Horvath, 2010).

Even though some IPs whom I interviewed struggled with formulating a precise definition of student engagement, all IPs in the study indicated that they were able to plainly identify when students were engaged in their lectures and readily described a felt sense of its occurrence in the classroom. The IPs reported particular behaviours exhibited by students in the classroom that were indicative of their engagement. These behaviours are presented in the next section as indicators of student engagement.

7.2 Identifying Student Engagement: Attention, Involvement, and Participation

During the interviews, some IPs spoke about the natural intuition required to identify the presence (or absence) of student engagement in the classroom. As mentioned in the previous section, nearly all IPs reported that they could tell when students were engaged during lectures. When asked how they could tell that students were engaged, IPs repeatedly responded that they could “see it in their faces” (IP1, IP4, and IP5). An important aspect of IPs’ facilitating engagement seems to be remaining cognizant of, and sensitive to, students’ behavioural output during lectures by facing the students, scanning the room, making eye contact with students, and being sensitive to students’ facial expressions in order to detect signs of confusion, inattention, boredom, or concern. As mentioned in the previous section, the IPs viewed the students as playing an active role in co-creating engagement; the students demonstrated their role as active participants through a variety of verbal and nonverbal behaviours that conveyed their simultaneous focused attention and involvement. The indicator of student engagement most frequently cited by IPs was participating publicly in the classroom by asking and answering questions or by showing effort to consider the questions being posed by the instructor. There were, however, other, subtler, behaviours that the IPs interpreted as cues indicating students' engagement. Because the IPs have an understanding of engagement as being comprised of students' focused attention, involvement, and participation, the cues that IPs use to identify student engagement are indicators of these three factors discussed below.

Attention. Students' focused attention is realized primarily through nonverbal cues such as appearing awake, attentive, and interested in what the instructor is saying; showing readiness to partake in learning (e.g., arms not crossed, sitting upright, ready to take notes); and by means of students' gaze directionality. According to the IPs, students' gaze directionality is indicative of their concentrated (on task) attention when focused on any one of the three key "players[24]" in the classroom: the instructor (looking at the

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[24] I use the term "player" here to refer to actors in the classroom context holistically to refer to both social actors (Norris, 2004, 2011; Scollon, 2001) and objects as actors (cf. Latour, 1996; Räisänen, 2015). This perspective enables researchers to consider "what agential powers the human as well as non-human entities may wield" (Räisänen, 2015, p. 140) over communication and social practices within a given spatial-temporal context.

instructor, following the instructor's movements, and making eye contact), the instructor's writing (on the chalkboard, whiteboard, or screen), and students' own notes.

Involvement. The IPs described students' involvement as realized through nonverbal behaviours such as writing in their notebooks, "active listening", and displaying comprehension or "following along". Thus, in the context of this study, involvement refers to students' mental activity around the material (i.e., they are thinking about and their thought processes are implicated in the material of the lecture). All the IPs said that they could tell if students were following along or they were lost. When asked how they could tell, most IPs said because they could "see it" (e.g., IP1, IP4, IP5). Some IPs elaborated that the understanding or comprehension was visible in the students' eyes, faces, and expressions, and others said, in the case of question-answer sequences, it was "obvious" in the moment which students knew the answer and which did not. Many of the IPs cited puzzled faces, furrowed eyebrows, and touching of the head or brow as indicators that students were lost. Previous research has indicated that touching of the head and face can be an indicator of "wondering" (Ekman & Friesen, 1969, p. 87), uncertainty, or a display of "conversational trouble" (Cibulka & Andrén, 2015, p. 190). Interestingly, though many of the cues that the IPs identified were nonverbal, they did not mention students' silence as an indicator of involvement, nor was it mentioned as an indicator of engagement. In fact, several IPs listed the sound of students talking to each other about the subject matter as an indicator of their involvement in the lecture.

Participation. According to the IPs, certain nonverbal behaviours are also indicators of students' active participation in lectures including producing facial displays that convey thinking or effort to formulate a response, nodding to show comprehension or respond to “checks” (when instructors check to ensure students grasp material, can see the board, have finished writing, etc.), and “getting animated” (IP2) or producing movement including raising their hands to signal their desire to contribute. Most prominently though, IPs described students’ participation as realized through asking and answering questions. All IPs cited “asking and answering questions” as an indicator of student engagement, namely, students’ public attempts at doing mathematics in the classroom (i.e., responding out loud to questions posed by the instructor about the mathematics written on the board). Asking and answering questions has been described elsewhere as the primary means by which students actively participate in chalk talk lectures (e.g., Paoletti et al., 2018; Viirman, 2014, 2015). Some IPs also specified that asking “interesting” (IP4) or thoughtful questions is an indicator that students are engaged in the lecture. Conversely, receiving no contributions from students was viewed by IPs as a key indicator that students are lost or not following along. This finding lends support to an observation made by Artemeva and Fox (2011) that students’ responses to questions acted as an important indicator used by instructors to gauge students’ learning whereas silence was viewed as a problem (p. 20). IPs also noted that behaviours such as avoiding eye contact by looking down or “hiding behind their screens” (IP4) (particularly after questions) were indicators that students were lost.

These findings are in agreement with research by Fredricks et al., (2016) that indicated that students and instructors in mathematics and science domains identified involvement and participation, hand raising and asking questions, paying attention and listening, demonstrating focus and concentration and showing effort as among the top indicators of student engagement. The researchers also noted that “students talked more about the importance of paying attention and focusing in math than in science. This may reflect the fact that math content was more likely to be taught sequentially in lecture-based formats, requiring students to build on what they have already learned" (pp. 9-10). Student and instructor participants of the Fredricks et al.'s study identified not participating, not asking questions, not paying attention or listening, not putting in effort, remaining silent, and "playing on phones" as behaviours that were indicative of students' disengagement (p. 9). In my study, several IPs identified elements of the learning environment that impeded their ability to make eye contact or otherwise interact with students as barriers to engagement, including students' use of personal laptops and smartphones. These and other aspects of the classroom context that have an impact on student engagement are discussed in the next section (Section 7.3).

7.3 Facilitating Engagement: The Classroom Context

This section draws together findings of Phases 1 and 2 with relevant research literature to discuss the ways in which the classroom context[25] can impact student engagement in chalk talk lectures. As discussed in Chapters 3 and 4, there is substantial empirical support linking such contextual factors as the learning environment and

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[25] As discussed in Chapter 4 in this dissertation, I include the learning environment (which involves factors such as class size, teaching mediums and technologies, classroom structure, and teaching style) and classroom climate (which involves teacher persona and student-instructor relationships) as aspects of classroom context. Many scholars use classroom context as an umbrella term in this way (e.g., Dotterer & Lowe, 2011; Fredricks, Blumenfeld, & Paris, 2004; Finn & Zimmer, 2012).

classroom climate[26] and student engagement (e.g., Bryson & Hand, 2007; Gasiewski et al., 2012; Scanlon et al., 2007). For example, the university mathematics learning environment has been argued to play a significant role in how students engage in mathematical thinking (Cardella, 2008; Flegg, Mallet & Lupton, 2012); and undergraduate students' physical and emotional proximity to the instructor has been associated with student engagement in university mathematics lectures (e.g., Bergsten 2011, 2012; Exeter et al., 2010; Shernoff et al., 2016). As discussed earlier (Chapters 1 and 4), the system of classroom practices is complex and co-constructed by the teachers and the students involved, and the nested contexts (Bavelas, Gerwing, & Healing, 2014, p. 3) through which they interact, thus, while there are aspects of the lecture classroom that may not appear to be directly linked to the realization of student engagement, I reiterate that the phenomenon of interest, like the overarching unit of analysis, is "part of a bigger system" (Matusov, 2007, pp. 326-27).

7.3.1 The learning environment: Teaching style and classroom structure

Throughout the data collection period, a theme that emerged was "the wholly interactive style of university mathematics teaching". Numerous SRs and IPs in my study reported that "very good" mathematics lecturers promote involvement and participation in the classroom by means of asking questions, involving students in the dialogue, and

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[26] Please note that in this chapter and elsewhere (e.g., Chapter 4), different aspects of the classroom context are presented as separate entities for the purpose of discussion but as mentioned in Chapter 2, Section 2.5, these aspects of the chalk talk context are enmeshed and interdependent; for instance, the teaching style used by an instructor may be impacted by class size and both may impact the overall classroom climate.

including students in problem-solving. Among the student responses to the Likert items, there was agreement that a good mathematics lecturer “asks questions” and “feels there is no question that is too elementary”. SRs and IPs alike noted the importance of asking and answering questions during lectures. Although it has been suggested that instructional approaches requiring student-to-student interactions and group discussion facilitate student engagement in various school contexts (Chi et al., 2018; Finn & Zimmer, 2012), there was little agreement amongst SRs in my study on the importance of the Likert items relating to class discussion and group work . These results exemplify that, while undergraduate students majoring in STEM disciplines may indicate a preference for active learning approaches to be incorporated into some core STEM courses (e.g., Gasiewski et al., 2012), chalk talk lectures may be one context in which such approaches to learning are not preferred by the majority of students nor are they necessarily useful (see, for example, Artemeva & Fox, 2010; Rodd, 2003). Despite no reports of a preference for active learning approaches, SRs and IPs made repeated references to the prominence of dialogue, eye contact, checking, using humour, and storytelling as engaging aspects of chalk talk lecturing, thus lending further support to this style of teaching as fundamentally interactive (see also Bergsten, 2011; Fogarty-Bourget, 2013). Also, while the results of my study did not explicitly reveal peer-to-peer interaction to be a construct of engagement in this context, other research has demonstrated that the chalk talk learning environment does evoke a sense of belonging and student community amongst undergraduate students who attend chalk talk lectures (e.g., Bergsten, 2011; Hubbard, 2007; Rodd, 2003) and there was some evidence of this communality in the

SRs written responses wherein a number of SRs expressed the importance of instructors teaching to “the whole class” rather than focusing “only on the best students”. Research suggests that in university lecture contexts, using interactive teaching styles that involve students, encouraging their contributions, and offering frequent feedback can create learning environments in which students are actively engaged in learning (e.g., Bullock et al., 2002; Gasiewski et al., 2012). As discussed in this and following chapters (Chapters 8 and 9), chalk talk lectures, particularly those taught by experienced, enthusiastic, and/or inspiring instructors (see also Artemeva & Fox, 2010; Fogarty-Bourget, 2013; Rodd, 2003), employ this style of teaching. Not only does frequent student-instructor interaction bring about student engagement in the classroom, it also demonstrates to students that their contributions are valued and gives them a space to feel seen and heard. Amongst the SRs and IPs in my study, instructor qualities that implied teacher sensitivity and immediacy, including demonstrating attentiveness, conveying a sense of “we’re in this together” (see Artemeva & Fox, 2010, p. 177), and seeming genuinely invested in students’ learning, were valued in university mathematics lecturers. Educational research places emphasis on the role of classroom organization and management in creating well-functioning learning environments at the levels K-12 (Hamre et al., 2007, p. 9). Even though, as Scanlon, Rowling, and Weber (2007) note, in the university lecture context students are expected to take more personal responsibility for their learning and be more independent than in high school learning environments, instructors are expected to play a role in classroom organization and management. Nonetheless, some IPs in my study struggled with classroom management and ensuring that students met their expectations for classroom conduct. In particular, IP4 found managing the behaviour of students in her first-year mathematics course for non-mathematics majors especially challenging. Despite efforts to make her expectations for classroom behaviour clear to the students, she experienced difficulties ensuring those expectations were met. IP4 did use classroom management strategies such as asking students to be quiet and meeting with students after class to discuss their disruptive behaviour (a strategy which she reported as being quite effective), she still had trouble getting the student body to focus and pay attention during lectures. At the time of the study, IP4 was teaching a first-year course (Differential Equations and Infinite Series) for engineering and physics majors. As mentioned in Chapter 4 (Section 4.2.2), in terms of student engagement, undergraduate engineering students in core undergraduate mathematics courses present a unique challenge to instructors because of the tendency to view mathematics courses as a burdensome requirement necessary to obtain their degree.

Indeed, most of the IPs that I interviewed discussed needing to use at least some management strategies to keep students paying attention and on task. Their strategies for managing classroom behaviour included overtly telling students to pay attention, thoroughly checking for comprehension and explicitly requesting feedback, and calling on specific students to regain their focus. Some IPs said that it was becoming more and more difficult to get feedback from students because of the pervasive use of student hand-held devices and laptops in the classroom. All the IPs whom I interviewed voiced concern over students’ use of electronics (namely laptops and smartphones) during their lectures. While some IPs were concerned that these electronics act as a potential distraction to students, most felt very strongly that students’ use of laptops and phones was problematic because it impeded the instructors’ capacity to gauge students’ levels of attention and/or understanding. According to some IPs, students' use of personal laptops compared to phones makes it particularly more difficult to tell what students are attending to. Several IPs said that it is easier or "obvious" to see that students are distracted or not paying attention when they are looking at or scrolling on their phones during lectures. These findings coincide with the findings of other research studies on student engagement in mathematics classrooms where teachers and students of elementary and secondary school mathematics and science classes identified "playing on phones" as an indicator of disengagement (Fredricks et al., 2016, p. 13), as well as research by Shernoff and others (2017) that found that students seated at the back of the lecture hall were more likely to be distracted by cellphone usage than students seated at the front of the room.

Research has shown that students may be more likely to disengage in classroom contexts that espouse a sense of anonymity (e.g., Scanlon, Rowling, & Weber, 2007) or where students are unnoticed or unseen. This means that the back rows of the lecture hall can be an environment particularly unconducive for students attempting to learn complex material (Shernoff et al., 2017, p. 63). IP2 said that when teaching in large lecture halls, it can be difficult to keep students engaged, especially beyond the first three rows of seating. He reported having to find strategic ways in such contexts to interact with students seated towards the back. One strategy he found to be effective was to systematically pick individual students to answer questions:

> I'll go from row to row, this is [a huge lecture hall] right? So you've got like 15-20 rows of students and I'll go okay today I start at row one, I have a question, so I'll

> be picking somebody from row one, now anybody that's not listening in row three's gonna have a problem here right? Cause you could be picking on him or her, they don't know who yer gonna pick on. So that usually helps. . . if there's somebody in row 20 they might not listen to you right away but you know that they- eventually they'll listen to you (IP2)

IP2 and IP6 actively worked to diminish any sense of anonymity that students in their classes might experience by referring to students by name, using playful nicknames, and acknowledging when students would enter and exit the classroom. According to the IPs, these strategies were used to help develop a positive classroom climate but may also serve to keep students' attention by promoting a sense of closeness and accountability. Lew and colleagues (2016) describe a university mathematics instructor participant in their study using similar techniques (e.g., systematically asking questions, referring to students by name) while lecturing to maintain students' focus and keep "their minds alert" (p. 23).

Throughout the interviews, the IPs described the issue of exceedingly large class sizes (i.e., teaching to huge groups of students) as a significant barrier to facilitating student engagement (cf. Cretchley, 2005). The IPs also listed time constraints, classroom configuration, and layout, namely, overly large lecture halls and/or insufficient board space (see also Maclaren, Wilson, & Klymchuk, 2018), as aspects of the learning environment that made engaging with students difficult. As university enrollments continue to increase, these issues are receiving a significant amount of attention. One way that universities have dealt with the exponential increase in student enrollments is by systematically converting many introductory courses from mid-size to large lecture settings (Bullock et al., 2002), offering online streaming of live or pre-recorded lectures (e.g., Howard, Meehan, & Parnell, 2018), or using “overflow” systems wherein broadcasts of the lecturer and their materials are projected from the main lecture theatre into adjacent lecture halls (Exeter et al., 2010). In all cases, the instructors’ ability to provide feedback and interact with students is diminished and students’ levels of attention and engagement in learning are negatively impacted (e.g., Bullock et al., 2002; Exeter et al., 2010; Howard, Meehan, & Parnell, 2018; Shernoff et al., 2017). Several IPs in my study noted that during lectures, ideally, they would interact more with students, ask more questions to gauge student learning, and promote more student participation, but that large class sizes and time constraints prevented them from doing so. Gasiewski et al., (2012) found that introductory STEM courses where faculty reported a lack of time to provide individualized attention to students had significantly lower levels of student engagement reported by students as did courses in which the instructors were perceived as being unavailable to students. Some IPs in my study observed that certain teaching strategies to facilitate student engagement, for example, having students participate by coming to the front of the classroom and writing on the board, are only possible with more moderate class sizes (one instructor suggested around 30 students). Additionally, IPs noted that the type of lecture halls required to accommodate class sizes of several hundred students made it difficult to see students seated towards the back of the room and made it difficult for students to see the board (see also Shernoff et al., 2017). These findings lend further support to studies that suggest that learning environments with smaller class sizes help to promote student engagement by creating more opportunities for student-instructor interaction (e.g., Finn & Zimmer, 2012; Gettinger & Walter, 2012). In certain teaching contexts such as condensed courses (wherein the content of a standard course is delivered over a partial semester) or introductory courses designed to accommodate several hundred students, required some IPs in my study to use teaching technologies such as document camera projectors (DCPs) instead of chalkboards or whiteboards to teach the lectures. As discussed in the next chapter (Chapter 8), these teaching technologies appear to have an impact on the classroom climate and student-instructor interactions in the classroom. In the next section, student-instructor relationships and teacher persona are discussed in relation to student engagement in the chalk talk context.

7.3.2 Classroom climate: Student-instructor rapport and teaching persona

As mentioned in Chapter 4, instructors in the classroom can portray specific teaching personae through various behaviours, personality traits, and ways of interacting with the students. The teacher persona, or "character" an instructor plays while teaching, can have a direct impact on the classroom climate (see Fox & Artemeva, 2010, p. 177-179). In the research literature, these instructor profiles are generally described in binary terms. In research on student engagement in STEM lecturing, Gasiewski and colleagues (2012) contrast "The 'Gatekeeper' Professor" with "The 'Engaging' Professor" (pp. 252-254); whereas in research on chalk talk lecturing, Artemeva and Fox (2010) describe the "welcoming" versus "distancing" persona, and Rodd (2003) distinguishes between a "Sage-on-the-stage" lecturer and a "Leader of minds" who draws students in and fuels their desire to learn mathematics (p. 18). In this section, I organize my findings in similar terms. First, I present the qualities that generate a positive classroom climate and student-instructor rapport, followed by qualities that can impede or hamper student engagement. It is important to note, however, that these behaviours and characteristics are presented in this way for reasons of organization and clarity, and that such qualities can be found in all varieties of instructors from very experienced, award winning lecturers to novice instructors teaching their first courses.

Cultivating a positive classroom climate. The SRs in my study were explicit about the characteristics and behaviours that contribute to a positive overall classroom atmosphere, many of which were also named by the IPs as important for facilitating student engagement in the classroom. Qualitative analysis of the written responses revealed that both SRs and IPs found it important for instructors to cultivate and maintain positive relationships with students. Strategies for doing so included *being patient*, *showing concern* for students' success, and *being sympathetic* to the student experience. Both SRs and IPs reported that "very good" instructors were approachable, friendly, supportive, and accessible. Artemeva and Fox (2010) suggest that instructor approachability supports students' engagement in academic work and that the perceived approachability of an instructor directly affects potential student-instructor interaction (p. 179; see also Scanlon, Rowling, & Weber, 2007).

Another behaviour that SRs in my study seemed to value was the use of humour and storytelling in the classroom; this was reiterated by IP2 who noted that he used stories as a way to maintain student engagement in the classroom. When asked if he could tell when students are engaged, he responded in a follow-up email:

> Yes, I think so. They look at me, they ask questions, they get animated and when they're bored I tell them a story. . . . They're all real stories and they have a marvelous effect, all of a sudden they look at you completely mesmerised as if nothing else existed. (IP2)

In the same interview, IP2 reported that he could see the students relax when he began to tell a story. Yet another IP said that he used humour as a way to establish a positive relationship with students and show care and concern for their well-being. Research on university mathematics teaching suggests that instructor's use of humour in the classroom is one of the most common strategies for promoting student engagement and interest in the chalk talk classroom, and can be very effective in increasing student engagement (Viirman, 2015, p. 1174; see also Artemeva & Fox, 2010; Bergsten, 2007, 2011, 2012). Using humour also contributes to a warm and welcoming classroom atmosphere (Artemeva & Fox, 2010) and students' perceptions of teacher immediacy. There is substantial empirical support for the value of teacher immediacy in university and college lecturing, and chalk talk specifically, in influencing undergraduate students' level of motivation and engagement in learning (e.g., Artemeva & Fox, 2010; Bergsten, 2011, 2012; Furlich & Dwyer, 2007; Gasiewski et al., 2012). In addition to the use of humour and personal asides, other instructor behaviours that have been linked to students' perceptions of teacher immediacy emerged from the data such as conveying enthusiasm and positivity while teaching (see Frymier, 1994; Furlich & Dwyer, 2007). SRs and IPs in my study reported that it was important that an instructor show passion and enthusiasm for the subject matter and the practice of teaching. Research suggests that instructors who are enthusiastic are associated with higher levels of student engagement and achievement (Bryson & Hand; 2007; Cretchley, 2005; Gasiewski et al., 2012). References to being “passionate” repeated throughout the qualitative data collected from both groups, while some participants specified that “very good” lecturers demonstrate “a genuine interest in the material”, are “nerdy”, and/or show an excitement for teaching and learning. Bryson and Hand (2007) suggest that high levels of enthusiasm and excitement about the subject matter and teaching, are a “prerequisite” for student engagement (p. 357). References to behaving positively toward students and teaching (e.g., helpful, having fun, laughing) were also repeated throughout SRs’ written responses and Likert items related to teacher immediacy were rated highly by SRs as qualities of a good instructor (e.g., is approachable, encouraging, friendly, and faces students when explaining material). These findings lend additional support to Bergsten’s (2007) observation that students place a tremendous amount of importance on “personalisation” in a mathematics lecturing (see also Anthony, 2000). The characteristics discussed thus far (e.g., approachability, enthusiasm, passion, joking and storytelling) reflect the observation made by Wood and colleagues (2007) that the instructor’s presentation of mathematics, “makes mathematics human, quirky and interesting; makes it worth doing” (p. 914).

Although it is important that instructors remain supportive, caring, and enthusiastic, my findings suggest that in addition, it is also necessary to maintain a professional and “masterful” persona. The SRs and IPs reported that a “very good” instructor is “personal yet professional”, confident, and demonstrates a deep knowledge base. As well, some IPs placed particular importance on maintaining a commitment to teaching quality and preparedness. Both groups agreed that it was important for instructors to appear knowledgeable, in part, through the ability to answer students' questions, understand a variety of approaches to the subject matter, and explain possible real-world applications. Because the SRs in my study were engineering majors, these findings reflect the argument made by Flegg et al., who suggest "engineering mathematics curricula should be designed to specifically target using mathematics as a tool for dealing with real-world problems" (p. 729).

Finally, as the findings presented in Chapter 6 show, the SRs and IPs in my study made evident the importance of presenting the material clearly and effectively. In the questions that used a Likert scale, the constructs "able to explain content clearly" and "speaks clearly" were among those rated most highly by SRs as attributes of a "good" mathematics instructor. Also, in their written responses SRs repeatedly cited speaking clearly and audibly and facing the students as qualities of "very good" mathematics lecturers. IPs as well noted that behaviours such as presenting material clearly, communicating effectively, looking at students, and making eye contact were of critical importance to effective teaching. This corresponds with the findings of research conducted by Wubbels and Brekelmans (2005) that showed instructors who spoke at an appropriate lecturing volume, scanned the classroom, and who held their head upright were rated by students as having high levels of influence (see Section 4.1.2) and were associated with higher student achievement outcomes.

Generating an "icy" atmosphere. In antithesis to a teacher persona that generates positive classroom climate, the SRs identified qualities and behaviours of a "not so good" instructor and the IPs identified aspects of chalk talk lecturing that they felt instructors could often improve upon. The behaviours and characteristics discussed in this subsection are those that contribute to an "icy" and strained classroom climate which can impede students' willingness to interact and engage in the STEM lecture classroom (Gasiewski et al., 2012; see also Watkins & Mazur, 2013). More specific to a chalk talk context, these qualities reflect a "distancing" teaching persona as described by Artemeva and Fox (2010) who observed that such behaviours can serve to generate an "icy" classroom atmosphere (p. 179).

According to the SRs, a "not-so-good" instructor demonstrates a negative stance toward students and teaching, and is perceived to be inattentive, unfair, and/or dismissive of students' needs and uncertainties. Interestingly, although this was a prominent theme that emerged from the written responses of the SRs, the IPs made no mention of feeling negatively towards their students. Most notably, however, the participants in my study identified the inability to present material clearly as problematic to successful chalk talk lecturing. The SRs in particular made reference to negative experiences with instructors whose writing on the board was unclear, messy, too small, and/or not visible to the students seated in the classroom. Among their responses were references to feeling frustrated by "small cluttered writing", "writing [that is] too small on the board and writing too quickly", and "terrible notes". One SR elaborated:

> She didn't speak clearly her notes were really messy on the chalkboard it made me very frustrated because what I had written wasn't correct due to messy notes on the board. I ended up failing the course.

Not being able to hear or understand the instructor was equally frustrating to the SRs. Several SRs mentioned that in some cases this was a result of English not being the instructor's first language, but others specified that they could not hear the instructor and cited problems with mumbling, speaking too quickly, and not providing sufficient time for students to respond (i.e., wait-time [Rowe, 1986]). Both SRs and IPs reported that a using a dull and dispassionate lecturing style and focusing too much on theory were qualities that could negatively impact student engagement. This lends support to Bryson and Hand's (2007) observations that when instructors lacked enthusiasm and simply "read off the slides" students reported feeling unengaged.

The IPs did not place the same importance on clarity of speech and writing as the SRs. Instead, the IPs identified qualities and behaviours that were more associated with lack of teaching experience as an aspect of lecturing that could typically be improved upon. These included feeling unprepared to provide sufficient explanations and/or examples, avoiding eye contact, and prioritizing delivery of the subject matter over listening to students. The SRs made reference to similar unfavourable behaviours such as presenting material too quickly, lacking confidence, exclusively following the textbook, making frequent mistakes, providing insufficient examples and/or unclear explanations, and not addressing students' questions. These findings lend support to research by Wubbels and Brekelmans' (2005) who found that teachers who were rated by their students as seeming uncertain and/or whose classrooms were disorderly reflected much lower student achievement outcomes than teachers who seemed assertive and confident. Interestingly, qualities such as lacking confidence, avoiding eye contact with students, focusing too much on the chalkboard and presenting the material over listening and interacting with students are qualities that novice instructors tend to struggle with (Amundsen, July 2016 and Aygin, May 2016, personal communication; Fogarty-Bourget, 2016, 2017; Wubbels & Brekelmans, 2005). Thus, many of the devices that instructors use to engage with students in the chalk talk context (e.g., looking at students, asking and addressing questions, waiting patiently for students to respond, and explaining concepts slowly and carefully) may develop with experience.

In the following chapters (Chapters 8 and 9), I present and discuss the multimodal rhetorical strategies used by instructors to involve students in doing mathematics in real-time and facilitate student engagement in the chalk talk lecture classroom. The data I use to inform Chapter 8 include video recordings of IPs teaching chalk talk lectures using a variety of different teaching mediums (see Chapter 5, Section 5.5.2).

Chapter 8: A Comparative Analysis of Teaching Mediums

The majority of university mathematics lectures observed and discussed in the literature are taught using traditional chalk and chalkboards or markers and whiteboards which are similar in terms of enactment (see Fox & Artemeva, 2012). However, a number of the recorded lectures investigated in this study were taught using document camera projectors (DCPs) or pen-enabled tablets (penTPCs). These teaching technologies permit the enactment of many of the key components of the chalk talk umbrella genre (namely, writing mathematical notation that is publicly visible while providing commentary, pausing the writing to provide metacommentary, and asking and answering questions). However, there are notable differences in the embodiment of the genre when such technologies are used (cf. Maclaren, Klymchuk, & Wilson, 2018). I include these data in my study for several reasons. First, regardless of the teaching medium used, rhetorically, the purpose of the genre is the same, that is, to teach mathematics to students in university in such a way that allows instructors "to perform the thinking and doing of the discipline in writing in real time" (Artemeva & Fox, 2011, p. 25). Thus, the strategies the instructors use help facilitate student engagement, in part by involving students in doing mathematics in the classroom, are rhetorically similar and therefore comparable. Second, while the IPs in my study were not opposed to the use of teaching technologies (some, in fact, embraced it), several IPs used teaching technologies in response to certain environmental pressures[27] despite their own reservations about how the technologies may

[27] These environmental pressures included the need to accommodate very large class sizes (where large lecture theatres made it difficult for students seated in the back to see the board) or condensed curriculums (wherein a lot of material needed to be presented to

affect their teaching. Essentially, a variety of new technologies are being used to teach university mathematics for various reasons not directly related and perhaps at some cost to pedagogical effectiveness and quality of teaching. Therefore, even if not the primary focus of the research, fine-grained multimodal inquiry of teaching practices pan-medium, particularly that of a comparative nature, is decidedly important at this time since only very few such studies currently exist[28]. For this reason, I have conducted a comparative analysis of two lectures taught by the same IP for the same course using chalk and chalkboard for one, and a DCP for the other. I present some of the key findings of the analysis below along with observations from the larger pool of data.

As mentioned in Chapter 5 (Section 5.6.2), analysis of the video data varied slightly depending on the phenomenon of interest being investigated and communicative modes being analysed. To conduct the comparative analysis, I uploaded the two lectures (one taught using chalk and one using DCP) into ELAN (Max Planck Institute for Psycholinguistics, 2017) and descriptively coded the data at the level of rhetorical moves

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students in a condensed period), or because they had experienced pressure from institutional administration to incorporate such technologies into their teaching.

[28] A study by Maclaren, Klymchuk, and Wilson (2018) compared penTPC enabled mathematics teaching with the results presented by Fox and Artemeva (2012) whose purpose was to demonstrate the recurrent nature of some key features of the chalk talk genre. Maclaren, Klymchuk, and Wilson (2018) collected video data of lectures taught using penTPC but, with the exception of a software-facilitated statistics lecture, did not themselves collect or analyse data of pure chalkboard or whiteboard lecturing (cf. Fox & Artemeva, 2012).

(Swales, 1990) (a meaningful chunk of text which expresses a single communicative purpose) and wrote analytical memos of potentially important behaviours and observations as I went along. I also descriptively coded nonverbal lower-level actions (Norris 2004, 2011) such as silences and pauses (i.e., silences occurring mid-utterance for fractions of a second). I analysed 1 hour and 22 minutes of each lecture (see Figures 12 and 13).

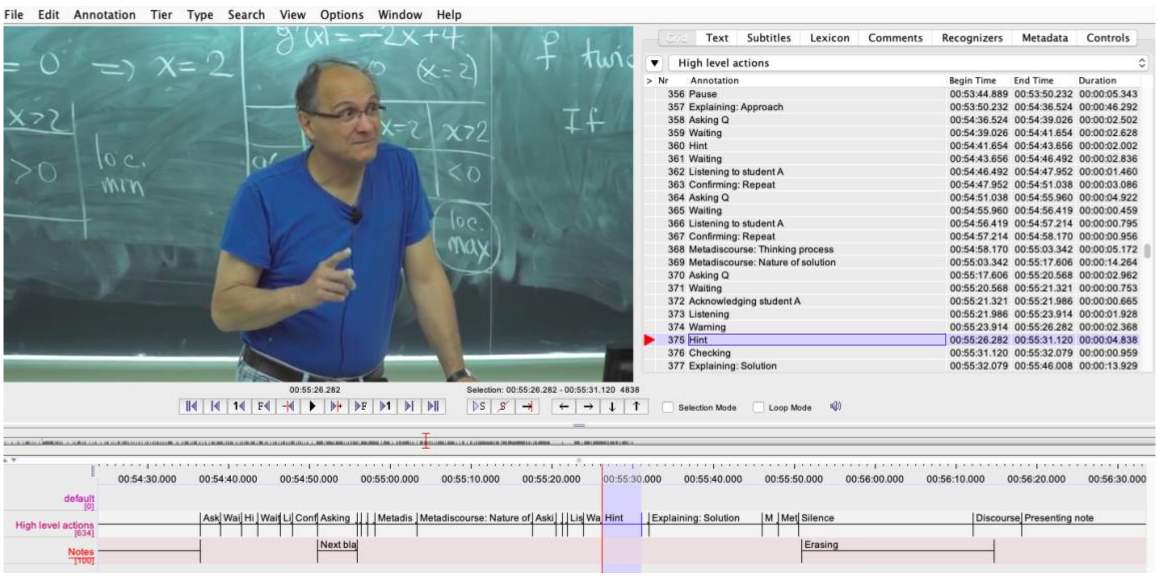

Figure 12. A screenshot of ELAN facilitated descriptive coding of video data of an IP teaching a lecture using chalk and a chalkboard.

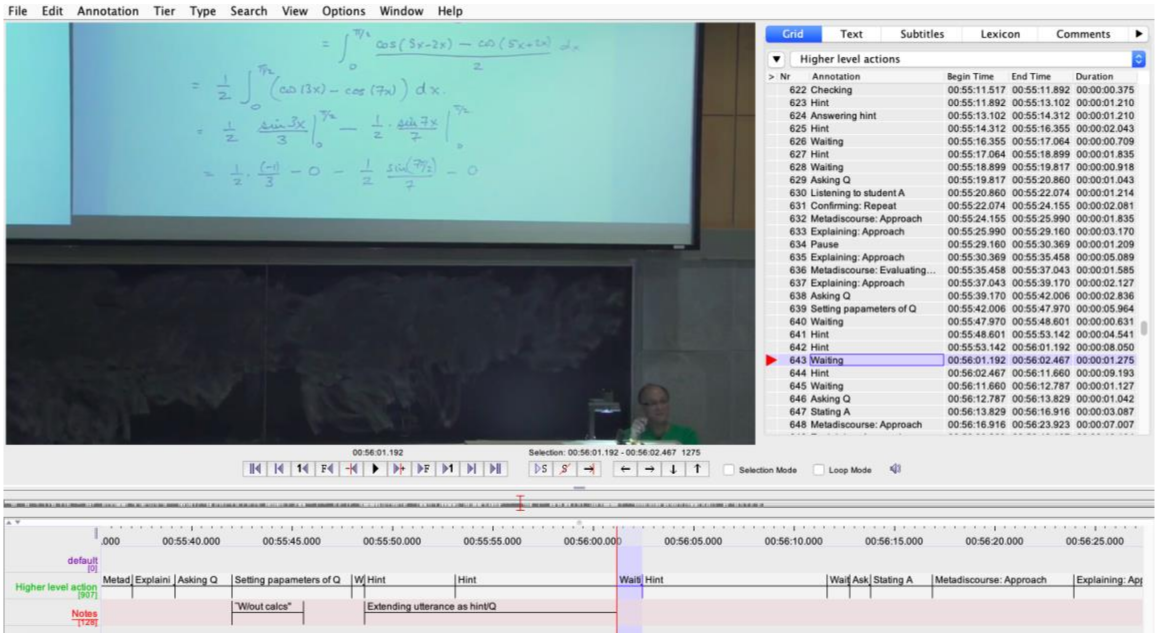

Figure 13. A screenshot of ELAN facilitated descriptive coding of video data of an IP teaching a lecture using a document camera projector (DCP).

Using ELAN, I tabulated the total number of occurrences of the different rhetorical moves and nonverbal actions and calculated the average duration (in seconds) of each occurrence. Thus, the data were “quantitized” to produce numerical tabulations and processed for statistical comparison (Dornyei, 2007, pp. 269-270; see also Plano Clark & Creswell, 2008, p. 281; Kitchenham, 2012). The quantitization of the data revealed the differences between the ways the two lectures were enacted. A detailed discussion of the all the differences is beyond the scope of this dissertation, but the key findings are presented below.

The comparative analysis revealed that the IP taught both lectures using all the same rhetorical moves, however, while the chalk lecture was enacted in the same way as described by Fox and Artemeva (2012) (see Chapter 4 Section 4.4.5), teaching with the DCP required that the IP be seated behind a large desk with a mounted projector and the lights be dimmed in the lecture hall so that the screens were more visible. When using the DCP, the IP would use many of the same gestures, as in chalk talk lectures, during mathematical explanations and question-posing sequences, however, his gestures were only visible to a small number of students who were seated in the first few rows, directly in front or to the right of the desk. For the majority of the students seated in the lecture hall, only the IPs head and face were visible. During an interview, the IP explained that he usually taught using chalk, however, the requirement imposed on him to teach a condensed version of the course (wherein, he would have to teach the regular amount of content in a shorter period of time) necessitated that he teach this course with the DCP. The IP noted that using the DCP he was able to write more mathematical notation without having to pause the lecture to erase the board; instead, with the DCP he could fill up a whole page with writing, and then replace the page and continue writing. As Table 4 shows, there was some time saved by using the DCP versus the chalkboard.

Table 4. Tabulations of the number of occurrences, average duration of occurrences, and total duration of time spent erasing the chalkboard (chalk lecture) versus manipulating paper (DCP lecture).

Move/Action	**Medium**	**Total occurrences**	**Average Duration (seconds)**	**Total duration**
Erasing the chalkboard	Chalk	26	14.8	396.2 (approx. 6 minutes)
Manipulating paper	DCP	17	6.3	99.8 (approx. 1.5 minutes)

While a small amount of time was saved by not having to erase the board (approximately 6 minutes spent on erasing the board versus approximately 1.5 minutes manipulating the paper), I observed that during the periods when the IP was erasing the boards, a particular variety of student-instructor interaction would take place. During moments of erasing, the IP would contribute personal asides or provide metadiscourse about the mathematics to the students at a more leisurely pace. Additionally, because erasing the board often brought about lengthier silences, the students would use the opportunity to ask questions, or perhaps, catch up on their notes or pause to reflect. Thus, the time that was saved using the DCP may come at the cost of certain important classroom behaviours. Interestingly, in the chalk lecture, many of the instructor-silences coincided with the IP's erasing of the board, whereas many of the silences in the DCP lecture coincided with the IP's writing of mathematical notation. From my classroom observations, I noticed that the students seemed to view the periods of clearing off the board as an appropriate time to ask questions, however, during the DCP lecture, the silences which occurred while writing were not treated by the students in the same way (i.e., they did not interject with questions while the IP was silently writing). As well, students in the classroom seemed to have a more difficult time gauging when to raise their hands to catch the IP's attention while he was using the DCP. Even though the IP was facing the students the whole time, he was often looking down at the paper and doing mathematics in what seemed to be a more solitary and focused way. In some cases, students raised their hands, and after some time lowered them again because the IP failed to take notice. These observations may have important implications for the teaching and learning of university mathematics in software-enabled classrooms.

The most apparent finding of the statistical comparison was that the lecture taught using the DCP involved more occurrences of most of the rhetorical moves and actions, all of which had a shorter average duration. Table 5 shows the total number of occurrences of mathematical explanation, checking, asking questions, and silence/pausing, and the average duration of occurrences in these categories.

Table 5. Tabulations of the number of occurrences, average duration of occurrences of the rhetorical moves and actions used in the chalk lecture and the DCP lecture.

Move/Action	Medium	Total occurrences	Average Duration (in seconds)
Mathematical explanation	Chalk	188	11.8
	DCP	254	8.0
Checking	Chalk	41	4.6
	DCP	60	2.6
Asking question	Chalk	70	6.6
	DCP	59	2.1
Silence/Pause	Chalk	46	5.7
	DCP	87	2.6

The statistical comparison revealed that, in fact, the IP not only saved some time by not having to erase the chalkboard, seemingly, the DCP sped up delivery of all rhetorical moves and actions included in the analysis. Importantly, one rhetorical strategy that did not correspond to this trend was his question-asking. The IP asked more questions in the chalk lecture than in the DCP lecture, and the duration of the question-asking was longer on average in the chalk lecture. There was still a lot of student-instructor interaction in the DCP lecture; however, the interactions mainly involved the small number of students seated near the IP who had good visibility of his person including his gesture-use.

The majority of the IPs in my study reported a strong preference for teaching with chalk and board for reasons having to do with pacing, timing, and the step-by-step process of teaching university mathematics (cf. Artemeva & Fox, 2011), as well as for facilitating student engagement. The following quotes are from excerpts from the instructor interviews:

> I think it's a very effective way to teach. It hasn't just sort of -it's not just by sort of historical default. I think it's because it's a tried and true method of communicating these key ideas because if you try to project a sort of a complicated technical proof on your overhead projector, or whatever, it's going to be hard not to miss some key ideas along the way, whereas if you're going through it sort of step by step *with* the class, then I think you are much more likely to present it in sort of a more intuitive way that the class can follow. And you can sort of give them a sense of what're the key ideas here. (IP1, his emphasis)

> I want to show students that process [of doing mathematics] that's what I use the whiteboard for is to show them how a real statistician works. . . So I regard education as a sort of gradual induction into a community of practice [of] mathematicians . . . so when I'm using the whiteboard what I'm sort of showing the whole class is "Look at this maths! Look, at this beautiful mathematics here" and the writing has got this sort of permanence, there's permanence, to it. Which has got my authority behind it. Now you flick over to the [penTPC/DCP] for a start *pause* yes, I'm facing the audience, but they see the top of my head, which is not particularly attractive. They see me interacting with a small square about 8"x5, which I don't think is very good *pause* if I'm writing stuff down like that, I may as well just give them what I'm writing rather than showing them how I'm writing

it. It doesn't feel right *pause* to try and interact with a large audience via a small device. (IP8)

I tried it [a projector]. . . and I didn't like it and I didn't feel that the students liked it as much *pause* I didn't find that I was able to engage them quite as much and also I tended to hover around the device rather than walk around . . . and so I always found that the spontaneity and flexibility of the chalkboard is more my style because I can change things too, very quickly. (IP6)

I think you can get more passionate with chalk, I mean your personality goes from the chalk onto the board, do you know what I'm saying? You can't do that with a PowerPoint you're talking and talking and talking and looking at this PowerPoint and not really creating anything new, people have to look at you, then look at the slide, whereas with the chalk . . . your chalk becomes an extension of who you are, just like a car is an extension of your body when you're driving it, and the chalk becomes an extension of you so whatever you put on that board is actually an extension of what you're doing and what you're thinking. (IP2)

I guess the whole point is that chalk *facilitates* not glossing over those key steps as much as it can still happen, but I think it facilitates it more to sort of turn it into sort of an interactive conversation where you're sort of working *with* the students and it's always a good opportunity, I think, to interact with the students and say, what do we do next? And give it a good amount of time to let the students sort of pause

> and think about it. Because that's that's what this is all about. That's *really* what we're trying to teach is the process as much as the final result. (IP1, his emphasis)

As these excerpts illustrate, the practice of teaching mathematics using chalk, or any writing utensil that preserves the embodiment of the chalk talk umbrella genre (see Fox & Artemeva, 2012), appears to be deeply connected to student-instructor interaction, student engagement, and teaching the process of doing mathematics. It should be noted that the IPs did also appreciate the ability to complement chalk talk lecturing with teaching technologies such as statistics software, computer generated visualizations, online real-time sharing software (e.g., BigBlueButton) or PPT slides as guided notes, in order to achieve what IP1 described as a “best of both worlds type scenario”. As mentioned, the IPs who did opt to use teaching technologies did so for a variety of reasons. One IP began complementing her chalk talk lectures with PPT slides that she provided ahead of time to students as guided notes when she realized that the students were not keeping adequate notes of her lectures. Another IP chose to use a DCP because the number of students in her courses required lecture halls so large that it made seeing the chalkboard difficult for the students in the back rows. Lastly, two IPs who did prefer chalk and continued to use it in their lectures spoke very seriously about the repercussions of working with and, in particular, inhaling chalk dust and the felt impact of decades of teaching with chalk had on their health. One of these IPs was actively trying to find a substitute for chalk that would behave in the same way as chalk but without the excess dust and with better visibility and easier clean-up than whiteboard markers.

At present, such comparative analyses of technology-mediated university mathematics teaching are absent from the research literature. The studies that do exist fall short of the fine-grained multimodal approach required to yield meaningful results and/or employ study designs that require more critical review (e.g., Bullock et al., 2002; Maclaren et al., 2018). The findings of this comparative analysis, while limited and preliminary, are significant and reveal aspects of traditional chalk talk lecturing that may prove important for student engagement in university mathematics teaching contexts. Additionally, and perhaps more importantly, they point to potentially problematic trends in higher education wherein changes to curriculum, classroom design, and teaching resources are being implemented without sufficient empirical support. More research needs to be done on a larger scale to determine all the ways that different teaching technologies shape university mathematics teaching and student-instructor interactions in this context. Nevertheless, this small-scale comparative analysis yielded results with important implications for university mathematics teaching and research; these are discussed further in Chapter 10 (Section 10.1).

In terms of including video data of lectures taught with different teaching technologies in the corpus used in this study, it is important to note that the DCP lecture included all the same rhetorical moves as the chalk lecture. The most obvious difference between the two lectures was their enactment as the DCP has different affordances compared to the chalk and chalkboard. These different affordances both enable and constrain the ways in which instructors enact the teaching of lectures and the verbal and nonverbal strategies used to realize student engagement in the classroom. The multimodal rhetorical strategies used by the IPs in my study to help facilitate student engagement in university mathematics lectures are presented in the next chapter (Chapter 9).

Chapter 9: Instructor Strategies for Realizing Engagement

As follows from the previous chapters, I define student engagement in the context of a chalk talk lecture as a state of sustained mutual activity wherein the students and instructor cooperate towards accomplishing the shared task of doing mathematics. In the present chapter, I respond to my final research question,

What strategies do instructors use to help facilitate student engagement in university mathematics lectures?

The data used to respond to this question include video recordings and classroom observations of chalk talk lectures, field notes, and follow-up interviews with IPs. The basic method used for conducting Qualitative Multimodal Thematic Analysis (QMTA) of these data is described in Chapter 5 (Section 5.6.2); however, the details of the analytical approach used for specific portions of the Phase 2 analysis are elaborated on throughout this chapter. The IPs in my study used various didactic strategies to engage with students in doing mathematics in real-time. The process of realizing student engagement in the chalk talk lecture classroom is three-fold; first, instructors establish and maintain a focused interaction (Goffman, 1963) with students in the classroom (Section 9.1); second, they involve students in the process of jointly doing mathematics (Section 9.2) by posing questions, creating a window for students to respond, and then finally encouraging students' public participation in advancing the mathematical narrative (Subsection 9.2.3). Instructors' strategies for accomplishing this process are presented and discussed in the following sections.

9.1 Establishing and Maintaining a Focused Interaction

As observed earlier (Chapter 4; see also Fogarty-Bourget, 2013), in chalk talk lecture contexts, instructors are in a constant, ongoing dialogue with their students. Some research (e.g., Gerofsky, 2010; Yoon et al., 2011; Yusof & Tall; 1998) has portrayed chalk talk lecturing as a one-sided transmission model of teaching wherein students sit passively while instructors blindly talk with little to no interaction with students. However, the current study indicates that, in fact, once chalk talk lecturers have established a focused interaction (Goffman, 1963) with the students in the classroom and begin the lecture, they steadily work to maintain the focused interaction as the lecture unfolds. A focused interaction, as previously mentioned (Chapter 2, Section 2.4.1), involves the mutual attunement of two or more social actors "joining each other openly in maintaining a single focus of cognitive and visual attention" (Goffman, 1963, p. 88; see also Kendon, 1978). Throughout a chalk talk lecture, instructors employ various engagement devices to maintain the focused interaction with the students; these include strategies for attracting and holding students' focus of attention and including them as discourse participants in the lecture. For student engagement to be realized in the classroom, the students and the instructor must jointly participate in doing mathematics; the focused interaction is the state of coordinated attention through which jointly doing mathematics can occur. In this section, I describe first, how instructors initiate a focused interaction with students, and second, how they work to maintain it throughout the lecture.

9.1.1 Initiating the focused interaction: Opening the lecture

Focused interactions (Goffman, 1963) can be initiated explicitly through talk, touch, bodily orientation, mutual gaze, or through any combination of these modes (see Andrén, 2014, p.160). The majority of IPs in my study established a focused interaction with their students by "opening the lecture" through a routine of discursive actions (cf. Viirman, 2014, 2015) that were remarkably similar. To investigate how the IPs in my study established a focused interaction with the students in the classroom, I conducted a multimodal rhetorical move analysis (Swales, 1990; Hyon, 2018; see Chapter 2, Section 2.2.1) using a multimodal approach to coding (see Chapter 5, Section 5.6.2) (Fogarty-Bourget & Artemeva, 2018). To conduct this portion of the analysis, I created a sub-corpus of all video recordings from Group A[29] (see Section 5.5.2) that captured the periods before, during, and after the "official" commencement of the lecture amounting to six recordings in total. I reviewed the recordings and, through memo-writing, gathered my initial impressions of the moves and steps involved in the opening of each lecture. I then uploaded the videos into ELAN (Version 5.0; Max-Planck Institute, 2017) and "marked and labelled moves" as described by Hyon (2018). That is, I highlighted segments of video whenever I observed the IP "performing a clear and interesting function" and annotated the segment by briefly describing the communicative purpose of the action being performed (p. 30) (see Chapter 2, Section 2.2.1 for a discussion of communicative purpose from an ESP approach). In some cases, I also marked sub-parts

[29] I used video recordings from Group A for this portion of the study because I was present at the time of recordings and kept detailed field notes of the goings-on in the classrooms. These field notes were essential to inform this portion of the analysis.

within those moves as possible steps[30] such when the sub-part appeared "crucial" to the move (Hyon, 2018, p. 30). From this initial phase of software-facilitated coding, I established a working set of moves (and steps when appropriate) and applied it to the sub-corpus adding additional moves upon discovery until all functional units were accounted for (i.e., until saturation was achieved) (see Figure 14 for sample of software-facilitated coding).

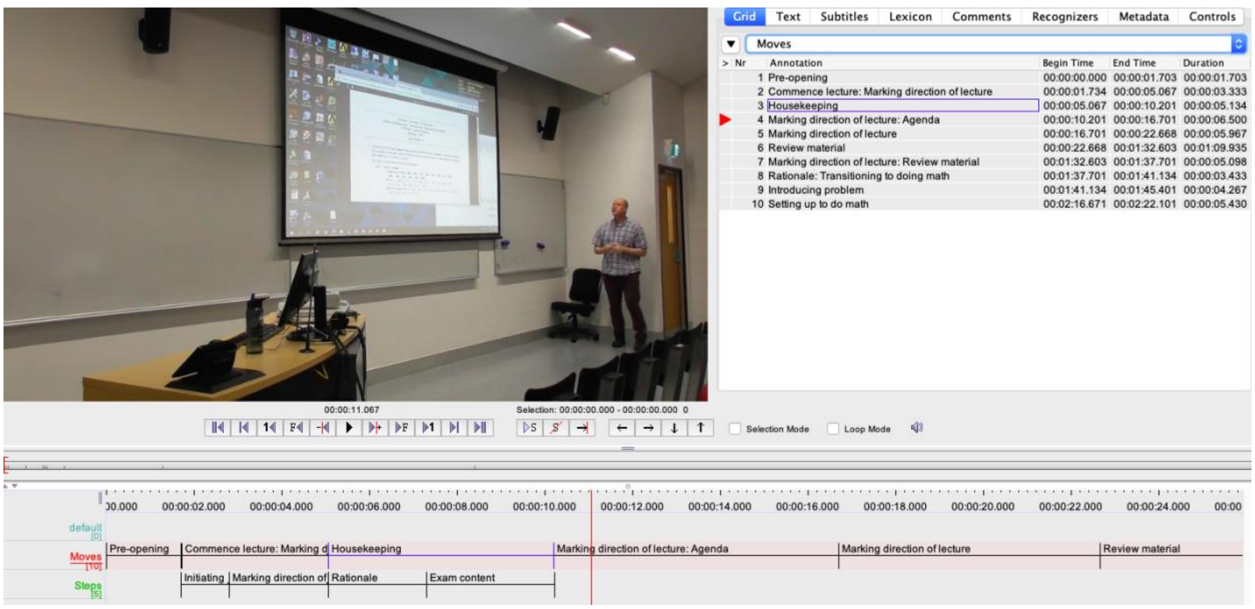

Figure 14. Example of software-facilitated multimodal move-step analysis.

After having coded all the segments, I noted frequency and sequencing of the moves (and steps) to determine if some moves had higher frequency and, therefore, were "more

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[30] In this analysis I generally did not go to step-level, since "opening the lecture" is a subgenre within the overall lecture, thus, moves identified within the routine are, in fact, steps in realizing the "opening the lecture" move of the umbrella genre of chalk talk (cf. Lee, 2009; Malavska, 2016 on the moves and steps of an academic lecture).

obligatory" (Swales & Feak, 1994) (i.e., "core" to establishing the move) than others, and any patterns in their sequencing (Hyon, 2018, p. 31).

The analysis revealed that the "opening the lecture" subgenre (cf. Swales, 1990 on introductions to research articles) is a recurrent component of the chalk talk umbrella genre and is comprised of a sequence of discursive moves enacted by the instructor, the majority of which are obligatory moves[31]. The subgenre of "opening the lecture" involves the following sequence of obligatory and optional moves (see Table 6):

[31] Several of the moves described here correspond to steps of the "Warming up" and "Setting up the lecture framework" moves of an academic lecture identified by Malavska (2016).

Table 6. Move-step sequence of "Opening the lecture" routine.

Moves/Steps	Obligatory/Optional
Pre-opening: Unfocused interaction	Obligatory
Commencing the lecture	Obligatory
Inviting student questions and/or attending to student questions	Optional
Housekeeping	Obligatory if any
Reviewing past material	Obligatory if any
Checking	Optional
Providing exam advice	Optional
Marking the direction of the lecture	Obligatory
(Step) Providing an agenda for the lecture or overall course	Optional
Setting up to do mathematics	Obligatory
(Step) Providing a rationale for doing the mathematics at hand	Obligatory
Transition to doing mathematics	Obligatory
Introducing the first problem	Obligatory

All of the lectures in the sub-corpus began by the IPs transitioning from an unfocused interaction with the students to a focused interaction in order to “officially” commence the lecture. Before the lectures commenced, the IPs and the students (which together formed the “participation unit”) were involved in a special kind of unfocused interaction – a “multifocused gathering” (Goffman, 1963, p. 90), wherein the members of the participation unit were involved in multiple engagements independently or with other participants (e.g., unpacking backpacks, checking phones, chatting, etc.). According to Goffman (1963), In such a context, the participation unit can exercise socially acceptable inattention (see pp. 83-87 on “civil inattention”). During this time, the IPs positioned themselves at the front of the classroom and prepared to open the lecture (e.g., arranged notes, classroom equipment, addressed individual student questions, etc.). Figure 15 shows screengrabs of three different IPs preparing to commence their lecture.

Figure 15. Screengrabs of IPs pre-opening the lecture.

When the they were ready to begin the lecture, the IPs initiating a focused interaction with the students by capturing their attention using speech, body positioning, and gaze. Initiating a focused interaction was often accomplished through speech using the discourse marker “okay, so”, addressing the students as a group (e.g., “you guys”), and individually by name when appropriate (e.g., greeting a student by name who arrived late) while briefly making eye contact (one IP in the study who was using a DCP did not make eye contact while establishing the focused interaction, instead he maintained gaze-directionality focused on the tablet). Figure 16 shows examples of three IPs initiating a focused interaction with the students to commence the lecture.

Figure 16. Examples of IPs establishing a focused interaction with the students to commence the lecture.

After establishing a focused interaction with the students, the IPs embark on a routine of housekeeping, reviewing material covered in past lectures, and marking the direction of the current lecture (and optionally, future lectures and/or providing a more detailed agenda) (cf. Young, 1990, on the discourse structuring of an academic lecture). Rather than treating students as merely audience members (cf. Rodd, 2003), the IPs in my study included the students as discourse participants in the lecture (and the overall course) by reflecting on shared knowledge (reviewing material), touching base about upcoming homework, assignments, and/or exams (housekeeping), and providing students with a roadmap of the lecture at hand (or agenda) (see also Lee, 2009; Malavska, 2016). Several IPs used the opening of the lecture to explicitly give students an opportunity to raise questions.

In my analysis, I observed a distinction between the commencement of the lecture, when the IPs shifted out of an unfocused interaction (pre-opening) into a focused interaction with the students in the classroom, and the commencement of doing mathematics, when IPs transition from the "opening the lecture" subgenre into the subgenre of jointly doing mathematics with the students. As part of the transition from "opening the lecture" to doing mathematics, all the IPs in the sub-corpus provided a rationale for presenting the material to the students (i.e., why it is necessary or important to learn the mathematics at hand). "Providing a rationale" appears to be a strategy used by the IPs to motivate the students to engage in doing mathematics.

9.1.2 Maintaining the focused interaction: Managing student attention

As discussed, previous studies have shown that chalk talk lecturing involves the instructor teaching mathematics by actually doing mathematics (e.g., Viirman, 2015) (see Chapter 4, Section 4.4), specifically, doing mathematics with the students in the classroom through cyclical episodes of problem solving (see Fogarty-Bourget, Pirini, & Artemeva, n.d.; Fox & Artemeva, 2012). After "opening the lecture", the IPs in my study began the process of doing mathematics with the students in the classroom by enacting the same cyclical routine as identified in previous studies of chalk talk lecturing (e.g., Fogarty-Bourget, Pirini, & Artemeva, n.d.; Greiffenhagen, 2008). The episodes consisted of the IPs first introducing a problem to the students in the classroom, then writing the problem on the chalkboard, then turning to the students to involve them in the problem-solving process (discussed in Section 9.2), and finally writing the solution on the chalkboard. Throughout this process, the IPs worked to maintain the focused interaction by making eye contact and looking around the room (in a pan-gaze), addressing the students (as a group or as individuals), and gesturing to and orienting themselves towards the students. Even when writing mathematical notation, the IPs worked to maintain the focused interaction with the students by providing commentary (Artemeva & Fox, 2010, 2011) (done in part so students may participate in doing mathematics in their notebooks without having to look up at what the instructor is writing), and using engagement strategies including gesturing to the students at different points on the board, glancing in the direction of the students, and changing the intonation of their speech.

To illustrate how the IPs worked to maintain the focused interaction with the students and involve them in the process of doing mathematics (Section 9.2), one problem-solving episode from the video corpus was selected for micro-analysis (i.e., extremely fine-grained, QMTA wherein all lower-level actions are included in the analysis). The excerpt was selected based on quality of the recording (i.e., the IP was clearly audible and visible and the writing on the board was clear and legible) but was otherwise comparable to other problem-solving cycles identified in the overall corpus. To conduct the fine-grained analysis, the excerpt was isolated and transcribed, and each lower-level action was descriptively coded[32]. The fine-grained analysis revealed that, in addition to providing commentary, gaze directionality, gesture, and facial display, the IP used instances of high modal complexity (Norris, 2004, 2011) to maintain the focused interaction with the students. In other words, the IP used a variety of devices concurrently in an attempt to maintain the communicative exchange while oriented towards the chalkboard. Figure 17 shows the IP using gesture, facial display/bodily orientation, gaze directionality, and intonation, in addition to speech and writing in an attempt to maintain a focused interaction with the students and hold their attention while he is writing on the chalkboard. The speech in Figure 17 is transcribed in the MIA transcription style where curvature of the text is used to convey intonation (e.g., text sloping upward represents rising intonation, whereas text sloping downwards represents falling intonation).

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[32] Coding was facilitated by qualitative coding software ELAN and NVivo 11 (QSR International, 2017). To demonstrate how such coding can be conducted without the assistance of coding software, this excerpt was also coded manually using paper and pencil as well as an Excel spreadsheet (see Appendix I).

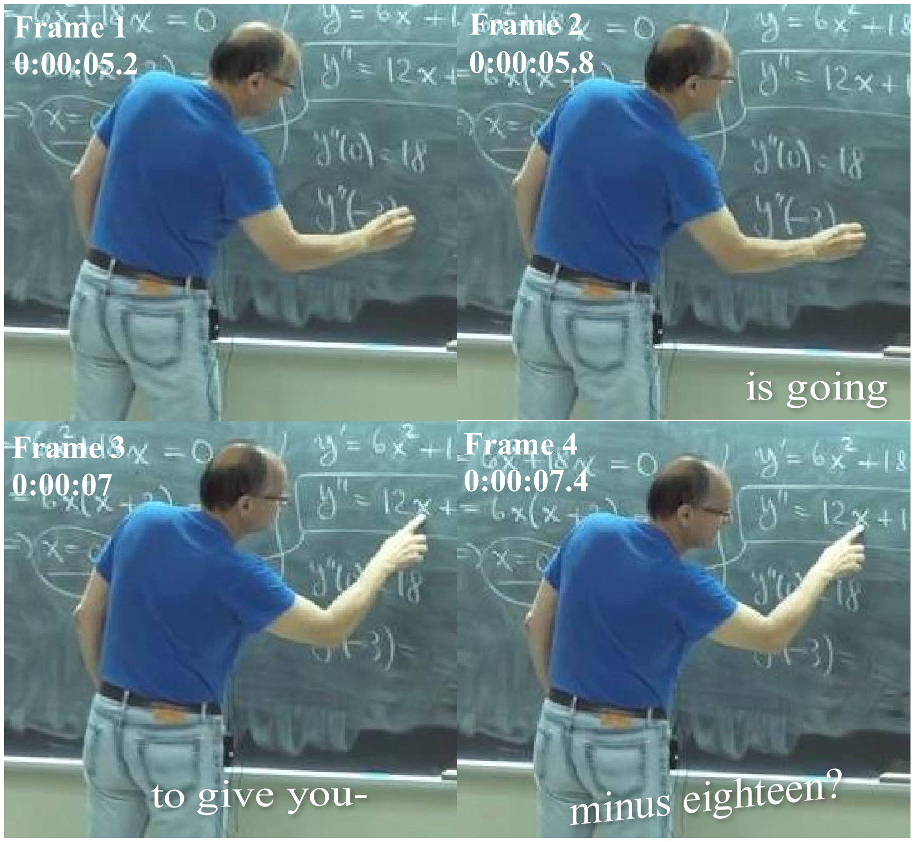

Figure 17. An example of an IP using modal complexity to maintain a focused interaction with the students while he is writing on the chalkboard.

The first frame (Frame 1) shows the IP writing mathematical notation on the chalkboard (Figure 17, Frame 1). He is oriented towards the chalkboard with his gaze focused on his writing as he completes the line of notation he has just articulated. In this moment, the IP is interacting with the students primarily through the mode of writing and spatial location (standing in front of them). When it comes time for the IP to complete the equation, he begins to articulate the mathematical process once again ("*is going to give you-*") and shifts his gaze to the line above (Frames 2 and 3). Instead of immediately articulating the answer, the IP elongates the personal pronoun "*you-*" (addressing the students), gestures to the line above, looks over his shoulder slightly in the direction of the students (Frames 3 and 4) and utters the answer with a rising intonation as though seeking confirmation from the students ("*minus eighteen?*") (Frame 4). The IP shifts from interacting with the students primarily through writing to interacting with the students through speech, gesture, gaze, and, to a limited degree, facial display, thus heightening the modal complexity (and, therefore, modal density) of the higher-level action. By addressing the students, posing a question to them, gesturing to focus their attention, and shifting his gaze in their direction, the IP seemingly attempts to reinforce to the students that they are discourse participants in the problem-solving process despite his orientation toward the chalkboard.

Another way the IPs worked to maintain a focused interaction with the students in the classroom was to use strategies intended to direct and focus students' attention to specific points in the mathematical notation or capture their attention while providing commentary and metacommentary. A number of these strategies were related to "chalkboard management" (Artemeva & Fox, 2011, p. 26), or to the strategic annotation of the mathematical notation made visible to the students (using DCPs or penTPCs for example). Artemeva and Fox (2011) note that, while chalk talk lectures are unfolding, instructors are "continuously cognizant" of the new writing on the board in relation to what has already been inscribed. These authors refer to the organization and strategic placement and annotation of the writing on the board as "board choreography" and identify it as an integral part of the chalk talk genre (pp. 15-16). The next examples show instances in which the IPs use textual devices (e.g., double underlining, bolding of certain fixed points, highlighting in boxes) to emphasize and contrast different dimensions of the mathematical notation, make prominent certain key pieces of text, and focus students' attention to specific points.

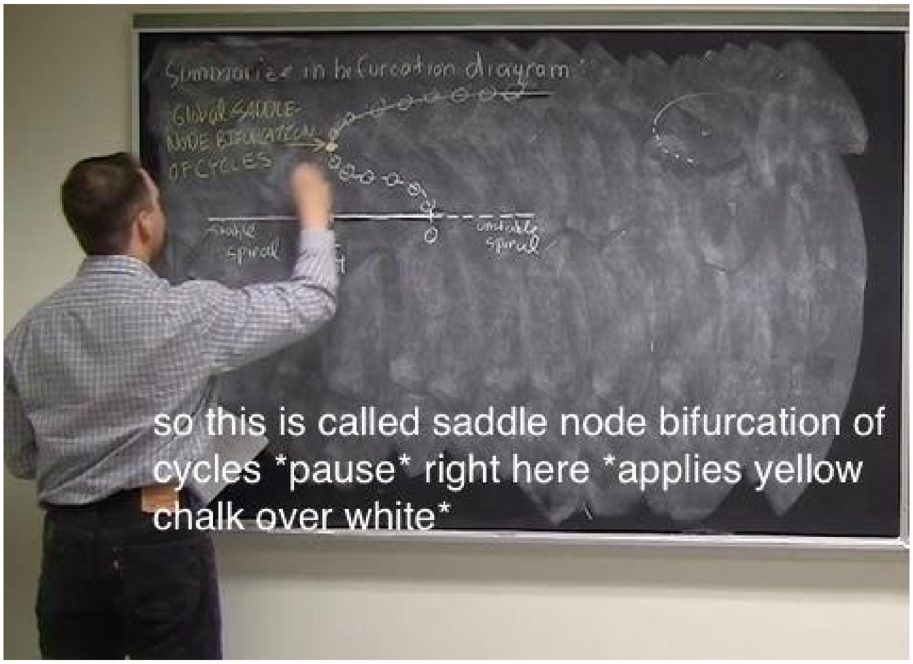

Figure 18. An example of an IP strategically using colour to emphasize certain key points on the board.

Figure 18 shows an IP using yellow chalk to emphasize a new bifurcation he has introduced to the students. Initially he has drawn the node with white chalk, then he asks the students to guess what the node might be called. Once a student guesses correctly, he enthusiastically repeats the correct answer “so this is called saddle node bifurcation of cycles” and reapplies chalk to the node in very bold yellow so that it stands out to the students. To further emphasize the point, the IP specifies “right here” as he applies the yellow chalk over top of the white. The next example shows an IP using colour and shapes to highlight a key point in the mathematical notation.

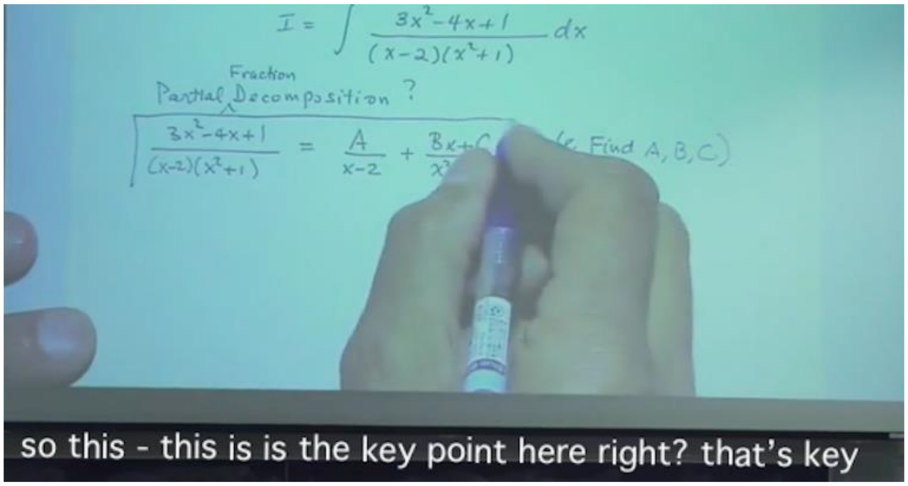

Figure 19. An example of an IP teaching with a document camera projector (DCP) and using colour and shape to highlight a key point.

The IP in Figure 19 is teaching with a DCP. In this example he is using a red pen to draw a box around a "key point" in the mathematical notation. In addition to articulating the importance of the equation, "this is the key point here right? That's key," and emphasizing the importance through repetition of the word "key", the IP uses colour strategically to indicate the prominence of the section of the text as a frozen-action (Norris, 2004, 2011) to make visible the emphasis. In the final example (Figure 20), the IP does not have access to coloured chalk.

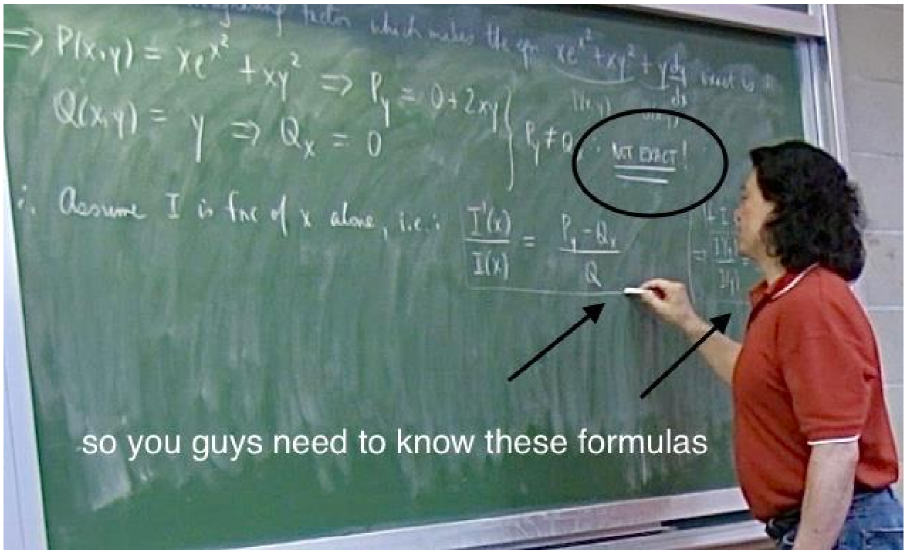

Figure 20. An IP using shape, punctuation, and underlining to make prominent key information.

Figure 20 shows an IP who only had a few pieces of white chalk available to teach the lecture. Like the IP in the previous example (Figure 19), the IP in this example also highlights "need to know" information for the students by drawing boxes around key formulas as well as using capitalization, punctuation, and underlining to emphasize key parts of the mathematical notation ("NOT EXACT!" written in the upper right corner of the chalkboard). By using these textual devices (e.g., colour, bolding, underlining) instructors can increase the salience of certain portions of the mathematical notation. In doing so, the modal intensity of the text is heightened (Fogarty-Bourget, Pirini, Artemeva, n.d.; Norris, 2004) at certain key points, and made more attention-catching and thus, more likely to be focused on or attended to by students in the classroom (Fogarty-Bourget, 2018; Fogarty-Bourget, Pirini, Artemeva, n.d.).

Finally, in addition to the use of textual devices, the IPs in my study used a variety of rhetorical strategies to capture students' attention and work to maintain the focused interaction including rhetorical questions, humour, and rich language. These pedagogical strategies have been identified elsewhere as means of directing attention, maintaining interest, and promoting student engagement (e.g., Artemeva & Fox, 2010; Bergsten, 2011, 2012; Viirman, 2015; Wood et al., 2007).

All the IPs in my study used rhetorical questions while teaching. Artemeva and Fox (2011) identified the use of rhetorical questions as a typified and recurrent behaviour of chalk talk, used by instructors teaching in different languages to signal transitions in the disciplinary narrative, pause for reflection, and/or as part of the metacommentary. Likewise, Viirman (2015) observed that all the instructor participants of his study used rhetorical questions while teaching university mathematics “mostly to direct students’ attention to specific steps in the reasoning or certain aspects of the mathematics worthy of reflection” (p. 57). The IPs in my study appeared to be using rhetorical question in much the same way, however, when asked about the use of rhetorical questions in a follow-up interview, IP1 said that he rarely used rhetorical questions even though the video data shows him using them frequently while lecturing. This supports Artemeva and Fox’s (2011) observation that much of the rhetorical action involved in chalk talk is engrained and embedded in lecturers’ enactment of the genre and as such, they are sometimes unaware of their discursive practices, nor do they typically reflect on them (p. 18; cf. Mason, 2000).

Some of the IPs in my study used humour, and/or “drastic language” (Viirman, 2015, p. 1174) while teaching. Viirman (2015) explains that in the long-term, the use of humour and dramatic wording or imagery can be used by university mathematics instructors to promote engagement and motivate students (see also Chapter 8, Section

8.2) but can also have a short-term effect of attracting the students' attention (Artemeva & Fox, 2010; Bergsten, 2011, 2012; Viirman, 2014; Wood et al., 2007). The following quotes exemplify how some IPs in my study used humour or dramatic language as a strategy to capture or focus students' attention at certain points in the lecture:

> "What's inside? **Look**[33]! This is extra-ordinary! Look, suddenly this is going to be, this is going to be the following equation…" (IP3, emphasis his)

> "Now, this is how it's going to finish, I find this extraordinary, **look**! Now I will reveal…" (IP3, emphasis his)

> "Using the *magic* formula *points to formula titled 'Life Saver'* I will write it again" (IP3, emphasis his)

> So the cosine gobbles up negative signs, that's the nice thing about the cosine function, it just eats the minus up rawr rawr rawr *grabs at the air* as if it wasn't there alright? But the sine function doesn't like the minus sign it just says '**go away**!' 'go out of my house' right? So the sine of B because **minus** the sine of B *pause* and that minus sign is stuck outside *pause* the door of the sine house, okay? (IP2, emphasis his)

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[33] Bolded text within participant quotes indicates direct speech is emphasized with increased volume (see Transcription Notations, p. xi).

"what's the indicial equation for that question? *pause* it's up there in the dark *pause* literally in the dark, in the rafters" (IP6)

"How do we find A? right? You know it's a math class but some of you may eventually go into engineering of some sort *pause* it would be sad but it may happen *group laughter* and you know you'd be given real functions" (IP9)

As the above examples demonstrate, in addition to humour, these IPs use discursive strategies such as clowning behaviour (e.g., IP2 acting out the 'hungry' cosine function), rich language (e.g., "This is extra-ordinary", "the magic formula"), or explicitly direct students' to attend to points on the board ("**Look**!", "it's up there in the dark") to capture and focus students' attention and also involve them in doing mathematics.

Lastly, to maintain the focused interaction with the students in the classroom, the IPs used a variety of strategies to make sure students were following along with the lecture. As mentioned previously (Chapter 7, Section 7.2), IPs reported that it was very important to check in with students, gauge their understanding, and remain cognizant of signs that students are lost or confused. In a post-recording interview, IP7 noted that those students who are lost or fall behind eventually stop coming to class all together, meaning that it is particularly important to identify signs of confusion early on in the course and during class time. Throughout the video data, I have observed all the IPs in my study regularly checked to make sure students were following along and understood the content. As has been shown (e.g., Fogarty-Bourget, 2013), instructors regularly check at various points throughout the lecture (e.g., after completing a line of notation, after arriving at a solution, during explanations, and before moving on to new material). They do so verbally by explicitly asking if students understand what has been presented, and nonverbally by looking at students, making eye contact, and using a pan-gaze (often paired with the discourse marker “Okay?”). The following quotes were drawn from video excerpts of the IPs in my study checking during lectures:

> So I suspect the Jacobian of the linear part composed with F, this is happening at X, to be BA *stops writing, faces students* *silence* *crosses hands in front and leans against wall* Everyone see what I'm doing? *pause* I think I’ve lost people *stands up straight, walks towards students, hands still crossed in front* Let's vote *raises hand high in the air* I'm lost *pause* *pan-gaze* Okay *drops hand* Let's back up (IP9)

> (after providing further explanation) Okay so *stops writing and turns to students* does that clear up, those folks who were lost, are you better now? *pause* Anybody *pan-gaze* so *raises hand partially, looking at students inquisitively, raises hand fully* let's vote, now I'm still lost *pausing, holding hand in the air* *pan-gaze* *pause* * I know that's hard to vote *pan-gaze* okay so let's go on *pause* so I expect Jacobian of GL composed with F to be BA. Let's prove this. How do you prove that? *stands facing class, hand folding behind back* Isn’t this fun? We get to use like all our techniques *pause* it's cool *pause* how do you prove this? *pause* how do you prove that the Jacobian is something you think it is? (IP9)

> *facing students, pan-gaze* But are there any questions beforehand? *silence* everything's cool? *silence* no questions? *pause* *pan-gaze* … Alright, so four point eight *writes on board* Newton's method *turn to students* um, so you did this in class already, right? No? Really? Well, okay, so the idea is… *writes on board, provides commentary*
>
> (after drawing a sketch and providing explanation) *facing students* "Does this make sense? *pausing, facing students, looking at students* *nodding* that makes sense? So *turns back to board* how do we actually find this?" (IP13)

The excerpts above are illustrative of recurring instances throughout the video data of IPs using multimodal rhetorical strategies to gauge students' understanding. Such strategies involve checking questions (e.g., "are there any questions?" "Does this make sense?"), bodily orientation (facing the students), gaze directionality (looking at the students and using pan-gazes), gesture (e.g., "let's vote" *raises hand*) and using repeated and extensive wait-time (Rowe, 1986). Viirman (2015) explains that these types of "control" or "comprehension" questions are one of the most common types of questions used by instructors in this context, and that they typically occur after a particularly important or complicated piece of mathematics has been presented or when the instructor is about to move on from one topic to another (p. 1175). Viirman notes that "only rarely do these questions actually generate a response in the form of a question from the students" (p. 1175), however, throughout my classroom observations I noted that such questions often did evoke feedback or participation from the students, though their contributions were not always verbal (e.g., nodding, head-tilting, looking puzzled, uncertain, or concerned).

In addition to checking, IPs in my study also used strategies involving annotation and chalkboard choreography (see Artemeva & Fox, 2011; Greiffenhagen, 2014) to make sure students could follow along with the unfolding mathematical narrative and to prevent them from getting confused. These include first, being careful to write the mathematical notation neatly and clearly while providing mathematical commentary. In an interview, IP2 explained the process of writing-talking with chalk:

> as soon as you stop that chalk you're thinking as soon as you write a symbol down, you're making sure it's being written correctly that it's not construed as being an alpha instead of an 'a' or an x instead of an alpha, right? and you're thinking about all these things. . . you have to make sure they're not misreading the symbols you're writing, so you're thinking about all that at the same time as you're trying to think of the best way to formulate the subject matter, that's the hard thing about board writing, if you don't have notes and I don't have notes. (IP2)

As mentioned in Chapters 6 and 8 (Sections 6.1 and 8.2), SRs in my study unanimously placed importance on instructors' ability to write neatly and clearly on the chalkboard and organize the notes in a way that is easy to follow. Thus, board choreography and attention to annotation appear to be important strategies for facilitating student engagement in the chalk talk lecture context. Another multimodal rhetorical strategy that IPs used to aid students' comprehension and make sure they could easily follow along, was the strategic use of colour in their board writing. The following examples illustrate the ways that IPs strategically use colour while writing to facilitate students understanding of the material. Figure 21 shows an IP strategically using colour throughout the lecture to contrast, emphasize, and differentiate different meanings within the mathematical notation written on the chalkboard.

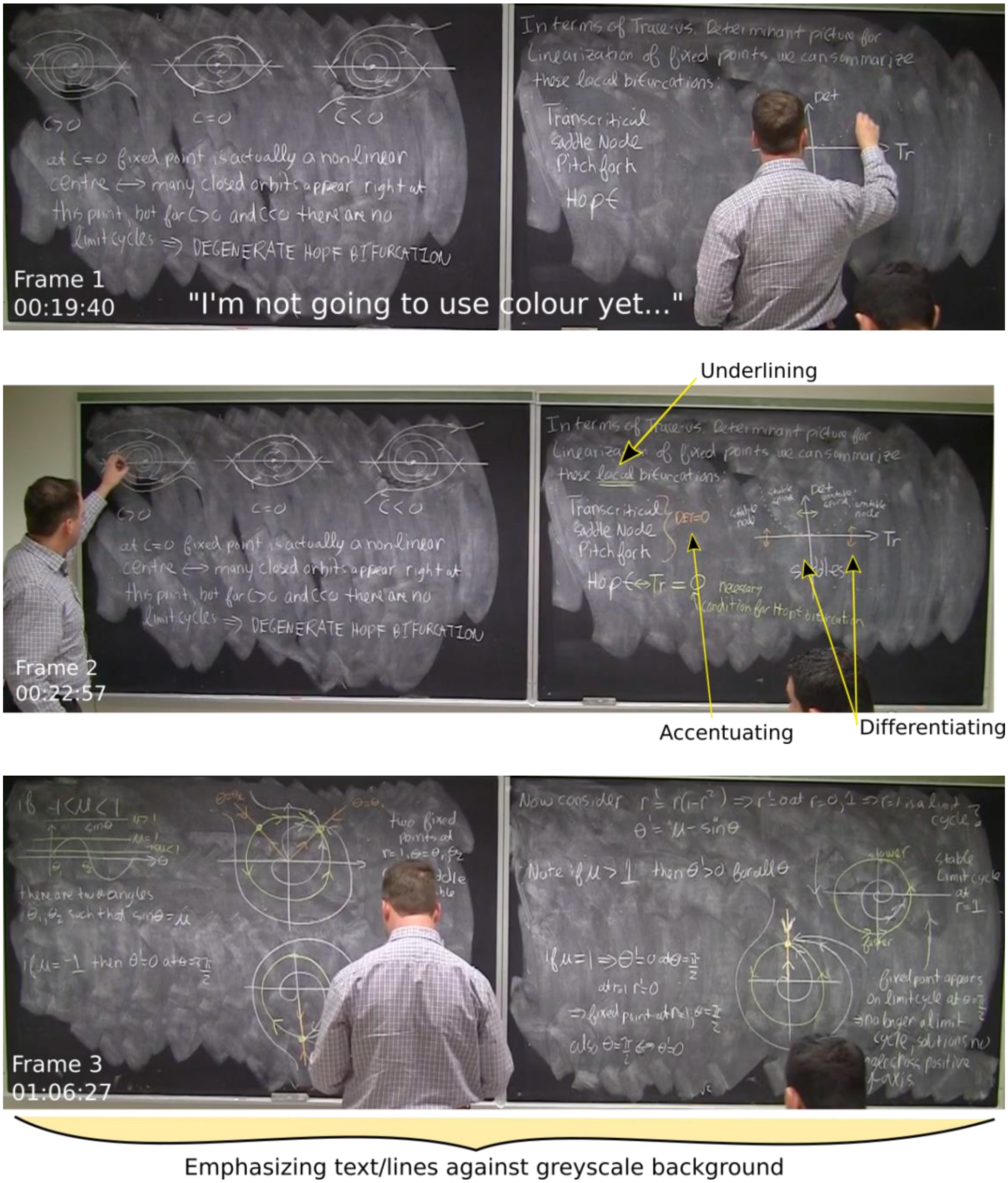

Figure 21. Examples of an IP strategically using colour throughout a lecture to contrast, emphasize, and differentiate different meanings within the mathematical notation written on the chalkboard.

Near the beginning of the lecture, as part of the IP's commentary (which includes the articulation of his thought process) he says out loud "I'm not going to use colour yet" (Frame 1). Later in the lecture, the IP uses colour strategically to emphasize parts of the mathematical notation. He uses different colours to annotate key components, underline to emphasize and show relationships, and differentiate points on a graph (Frame 2). As the lecture unfolds, the IP uses coloured chalk to emphasize the radius and direction of limit cycles against the greyscale background of the chalkboard and to make prominent certain fixed points on the limit cycles (Frame 3). In a follow-up interview, the IP explained his use of coloured chalk in that instance:

> so why do I use coloured chalk? I use coloured chalk to contrast certain things like if you've got a plot with multiple curves and one curve represents one thing and another curve represents something else then you need colours to sort of bring out that dimension . . . in that course there are times when you've got quite complicated visualizations of, you know, mathematical techniques for proving certain things. . . . so often before the lecture I will think ahead and think where will I need colour and how many colours will I need? . . . what I was doing was thinking ahead and thinking I don't want to use the colours now because I'm gonna need that colour and that colour will have a meaning later in the lecture and I don't want to confuse the students by using the colour here for one thing and then there for something else, because I try to be consistent.

Similarly, IP2, while switching colours of chalk during a lecture, articulated his pedagogical thinking process which is interwoven into his mathematical thinking process:

> Now for the local maximum, I'm going to make the local maximum a different colour because that'll make it easier to see *pause* so for local max the test…right so the left of C so now we'll make another picture remember the picture's there to help us remember right? Okay we have a local maximum here. (IP2)

These examples illustrate, on one hand, multimodal rhetorical strategies that the IPs use to help students to follow along with the mathematical narrative being written on the chalkboard, and on the other hand, aspects of what Viirman (2014) describes as *the discourse of mathematical teaching* wherein instructors use various pedagogical devices to increase student attention and understanding of the mathematical discourse. For example, in addition to articulating what is being written on the board, and the thinking process involved in doing the mathematics being written, the IPs' commentary often includes articulating aspects of their pedagogical thinking (e.g., "I'm not going to use colour yet", "I'm going to make the local maximum a different colour because that'll make it easier to see"). In the same way that the "opening the lecture" routine functioned to include students as discourse participants in the lecture, the articulation of pedagogical decision-making includes the students as discourse participants in the pedagogical genre of chalk talk and helps to involve them in the process of doing mathematics together with the instructor. In the next section (Section 9.2) I further discuss instructors' strategies for involving students in jointly doing mathematics.

9.2 Involving students in doing mathematics

Capturing students' attention to establish a focused interaction (Goffman, 1963) is a precursor to a core component of student engagement in chalk talk lectures. Greiffenhagen (2008) describes chalk talk lecturing as a "recipient-designed demonstration of mathematical reasoning" resembling a familiar master-apprentice situation (p. 15) where the mathematical skills are taught somewhat indirectly, namely by an experienced mathematician doing mathematics in the lectures and novices (i.e., students) observing and doing mathematics themselves simultaneously in real-time. As discussed (Chapter 2, Section 2. 3), this type of situated learning (Rogoff, 1990) necessarily entails students' active participation in ongoing social activities. In the chalk talk lecture context, learning occurs through a process of communication and shared participation, where instructors challenge and support learners in the process of posing and solving problems (i.e., the cyclical problem-solving routine described in the previous section). Thus, the essence of teaching university mathematics is binal; that is, a) doing mathematics publicly in the classroom so students can observe the process (i.e., see and hear the writing-thinking-doing) and b) involving the students in jointly doing mathematics in real-time. The mathematics that the instructors jointly do *with* the students are slightly more ahead of what students can accomplish alone and thus challenge and lead students' learning so that they may eventually do the mathematics independently outside the classroom. Instructor strategies for involving students in doing mathematics in the classroom are discussed in this section by presenting examples of IPs posing questions to students, indicating the need or desire for a response, creating a window for students to respond, and, when necessary, encouraging or applying pressure on students to participate by contributing publicly to the mathematical narrative.

9.2.1 Posing questions and signalling for responsive action

In chalk talk lecturing, the primary means of involving students in doing mathematics is asking questions, that is, through the Socratic method of teaching (see Polya, 1957, 1963; Rhee, 2007; see also, Mason, 2000; Speer, 2008; Viirman, 2015). The practice of posing questions (specifically turning from the chalkboard to face the students and asking questions) has been identified as an integral component of chalk talk lecturing (Artemeva & Fox, 2011; Fox & Artemeva, 2012; Speer, Smith, & Horvath, 2010). Previous research on university mathematics teaching (e.g., Mason, 2000; Paoletti et al., 2018; Speer, 2008; Viirman, 2015) has identified variation in the type and amount of questions instructors ask while teaching. Rhetorical questions have already been discussed as a strategy for directing students' attention (see Section 9.1), however, questions which require a response from students[34], namely, those soliciting contributions from students towards jointly doing mathematics (i.e., mathematical questions) and

[34] Paoletti and others (e.g., Paoletti et al., 2018; Viirman, 2015) have identified multiple different types of questions that university mathematics instructors pose to students. While their research is indeed useful, this is not the focus of the present study, thus I make only a simple distinction between rhetorical questions (those which do not intend a response), mathematical questions (those intended to solicit contributions from students towards jointly doing math), and checking questions (those which explicitly seek feedback regarding students' comprehension and/or progress).

questions to gauge student comprehension (checking questions) encourage students' active (and often public) participation in the chalk talk lecture.

All the IPs whom I interviewed reported that they ask questions to students with the intention to encourage their participation in the lectures. In my Master's research (Fogarty-Bourget, 2013), I observed that posing mathematical questions was the primary way that chalk talk lecturers (both novice and experienced) elicited participation and feedback from students. Similarly, all the IPs in the present study posed mathematical questions to the students throughout the lectures although, in agreement with Paoletti et al. (2018), some IPs asked more questions than others[35]. I observed that IPs generally *did* pose questions to provide opportunities for students to participate (cf. Paoletti et al., 2018, p. 14) and that they did so as part of the cyclical problem-solving routine described earlier. That is, the IPs would provide some metacommentary to introduce the problem and explain what is about to be done, and then pose questions (in writing, speech, or both) to sequentially work through the problem by soliciting contributions from the students. They would continue this process until all or part of the problem was

[35] The majority of IPs in my study regularly asked questions throughout their lectures with the exception of one IP who asked questions only occasionally. This behaviour was consistent with how he viewed the main purpose of university mathematics lectures which was to demonstrate to students the process of doing mathematics (cf. Iannone & Nardi, 2005; Sfard, 2014). He did say in the follow-up interview that he felt participation was important and that he posed questions to the students to encourage participation, but was not necessarily sure lectures were the appropriate environment for asking and answering questions.

completed, and then write the solution out for the students to see before finally providing metacommentary to summarize what had been done and, if applicable, how it will be used in subsequent parts (see Greiffenhagen, 2008, p. 15) of the mathematical narrative. Figure 22 shows an example of an IP posing a question to the students in the classroom in speech and writing to involve them in doing mathematics.

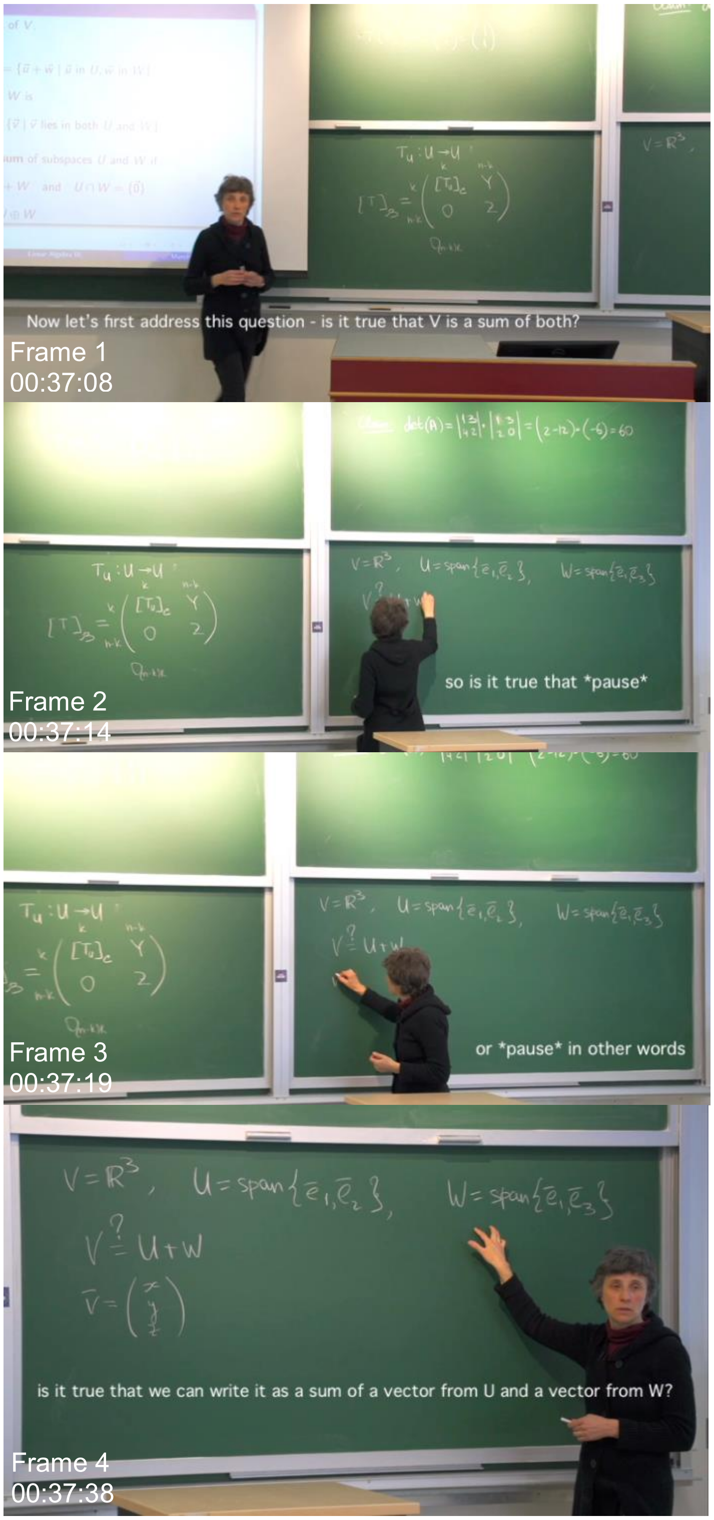

Figure 22. An example of an IP posing questions to students in speech and writing to involve them in doing mathematics.

After proving some metacommentary to situate and introduce a problem to the students in the classroom, the IP in Figure 22 explains what needs to be done to arrive at a solution (“Now let’s first address this question”) and then poses the overarching question “is it true that V is a sum of both?” (Frame 1). She then *materializes* (see Greiffenhagen, 2008) the question in writing (Frame 2). After turning to the students briefly, she rephrases the question in writing and articulates what she writes (Frame 3). Lastly, she reposes the question in speech “is it true that we can write it as a sum of a vector from U and a vector from W?” while referring with a deictic gesture to the mathematical notation (Frame 4). In the span of less than 30 seconds, the IP in this example posed the question (and variations of the question) four times using speech and writing. The final iteration of the question (Frame 4) is the one that intends a response from students. The previous multiple iterations of the question are used to include the students as discourse participants (e.g., “Now let’s first address this question) and encourage their active involvement in jointly doing mathematics (by means of their thinking about, observing, and writing in their notebooks the mathematics being done on the chalkboard). This sets the stage for the final iteration which enlists the students in doing mathematics through their public contributions. In other words, the initial iterations are used to involve the students in different ways in doing mathematics privately, while the final iteration creates a need (or *exigence* [cf. Miller, 1984]) for responsive action from the students, that is, “making public” their involvement in doing mathematics in order to advance the mathematical narrative (cf., Miller, 1984, p. 30). Viirman (2015) notes that grappling with mathematical questions in this way “keeps the students engaged and active, and involves them in the actual process of doing mathematics” (p.1776). In an interview, another IP (IP6), spoke to the effectiveness of asking questions in this way and the Socratic method in general:

> This is why the Socratic method works so well -- because when you ask them [the students] directed questions, you are *drawing* out the material from them. Now, clearly in math, you can't draw out every complicated formula or differential equation or what have you. But you can draw out the concept, the general concepts from them [the students] by asking you engage them, you get their minds working *forward* on the material rather than just memorizing material, rather than just listening to you and trying to remember it, you get them to *create* the lesson. (IP6, emphasis his)

In Figure 22, the IP's initial posing (in speech), and subsequent materialzing (in writing), rephrasing (in speech and writing), and final reposing (using speech, writing, and gesture) of the question, are rhetorical "steps" of the question-posing "move" (Swales, 1990) in the problem-solving routine, the communicative purpose of which is to engage with students in doing mathematics. This is important to note as some empirical studies (e.g., Paoletti et al., 2018), though useful, first, are often not informed by rich multimodal and video data and thus cannot account for the modal complexity of certain question-posing sequences; and second, depending on the theoretical and/or analytical approach taken, may not consider the communicative purpose(s) of such rhetorical actions. This may lead an analyst to misinterpret the sequence as multiple questions posed quickly and without sufficient wait-time (Rowe, 1986) instead of as steps that contribute to a single question-posing move.

When instructors do intend a response, they use a variety of strategies to signal their intention to the students[36] (Fogarty-Bourget, 2013; Fogarty-Bourget, Artemeva, & Fox, 2019). These include turning to the face the students after posing a question, providing wait-time, looking around the room (pan-gaze), and using specific interactive gestures (e.g., open-hand gestures that imply a willingness to receive information) (Fogarty-Bourget, 2013). In agreement with the findings of my Master's study, the IPs in the present study used all these same strategies to signal that they desired a response from students (i.e., students' public participation in doing mathematics). Figure 23 shows the same IP using a variety of these strategies to signal to students that she intends a response from the students.

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[36] While there are specific points throughout the lectures when instructors explicitly signal to students that they desire their feedback and participation, as Fox and Artemeva (2012) note, "at any point in chalk talk students may interrupt the flow of action if they notice an error or want to comment" (p. 93).

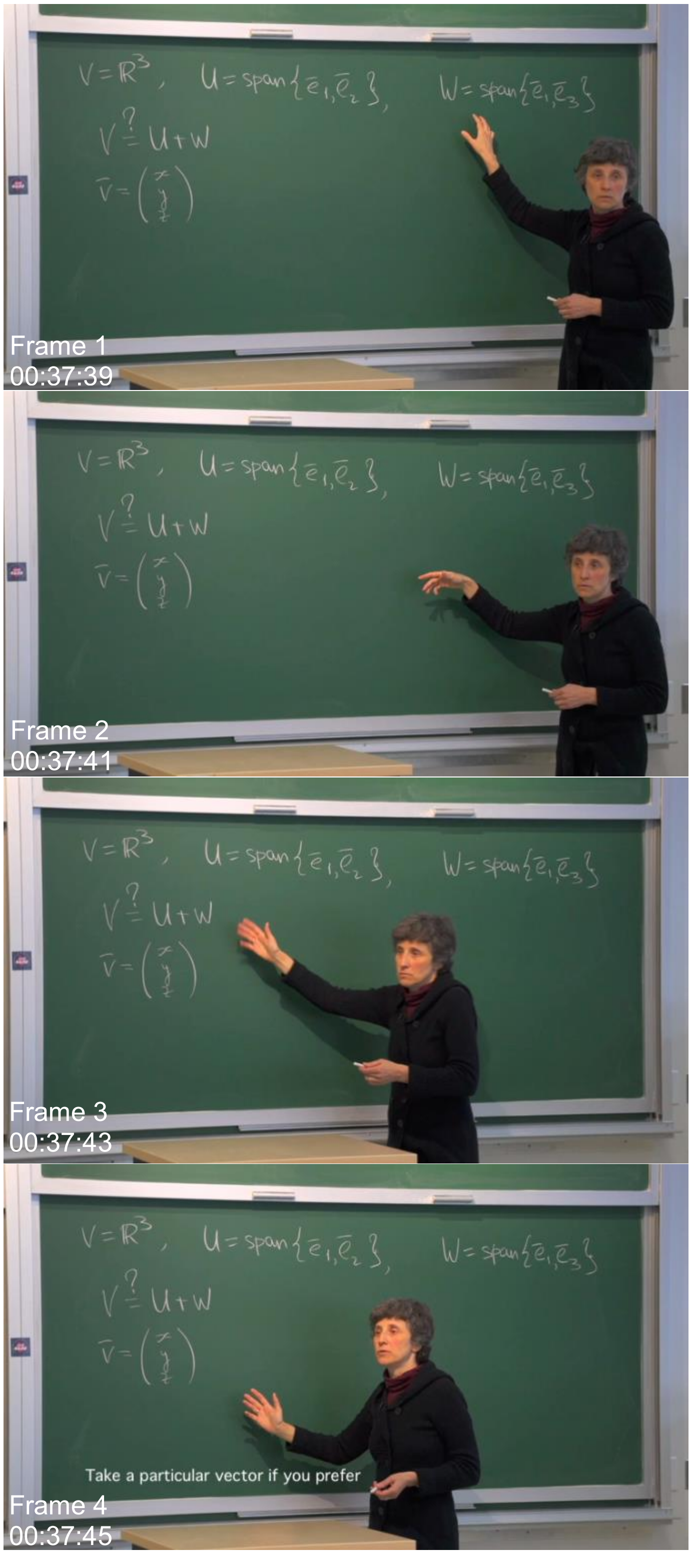


Figure 23. An IP using bodily orientation, gaze directionality, wait-time, and gesture to signal to students in the classroom that the question she posed intends a response.

After posing the question to the students, the IP provides wait-time where she stands silently, without moving, and looks towards the students seated in the classroom (Figure 23, Frame 1). After 1.5 seconds, she drops her right hand slightly and looks around the room in a pan-gaze (Frame 2), she then starts to gesture with her right hand in an open-hand (palm-up) gesture (Frame 3) that implies a degree of obviousness and that the receiver is free to act, in this case to "take a particular vector" (Frame 4). In doing so, she makes clear that the question being posed has been offered up in the "conversational arena" (Kendon, 2004, pp. 280-281). Before making the suggestion that students take a particular vector, the IP provides just over 5 seconds of wait-time.

In addition to the strategies described here and elsewhere (Fogarty-Bourget, 2013; Fogarty-Bourget, 2018) my research has revealed a nonverbal engagement device, which I refer to as *gestural silence* (Fogarty-Bourget, 2016, 2017; Fogarty-Bourget, Artemeva, & Fox, 2019), used by instructors to involve students in doing mathematics by creating a window or space for students to provide feedback and/or mathematical contributions.

9.2.2 Creating a window for students to respond: An exploratory study of gestural silence

In my previous research (Fogarty-Bourget, 2013, 2016), I observed that university mathematics lecturers use gestural rest positions (when the hands are held still) in what seemed to be a particularly meaningful way. However, a dearth of relevant research literature presented an impetus for empirical research on the phenomenon. Here, before discussing the findings of the investigation, I present a brief overview of the existing literature of gestural non-movement including rest positions, followed by additional details regarding the methods used in this portion of the study[37].

Until recently, rest positions have been largely excluded from gesture studies. Only in the past few years have gesture researchers (e.g., Andrén, 2012; Bressem & Ladewig, 2011; Cibulka, 2015; Ladewig & Bressem, 2013; Svinhufvud, 2018) begun to shift their attention from the stroke itself to other phases of gesticulation, namely, holds and retractions, in an effort to learn more about their communicative properties and roles in face-to-face interaction. Despite the growing number of studies focusing on the individual gesture phases (e.g., Andrén, 2012; Bressem & Ladewig, 2011; Cibulka, 2015; Ladewig & Bressem, 2013), relatively little attention has been paid to those phases which are not accompanied by movement. For example, Cibulka (2015) has investigated the "intermediate positions of non-gesturing" that occur following the stroke but before full retraction (Cibulka uses the term "home" to refer to a rest position). He defines the spatial location where the hands produce gestures as the gesture "stage" which "denotes the actual location where the stroke is performed" (p. 5) and describes two phases of non-movement that occur in midair – provisional home positions and prolonged hold phases that stretch over speaker turns. Speakers appear to use the provisional home position to create a "momentary suspension of their pursued line of action and produce a 'just-for-now' stance" (p. 20). Further, Cibulka states that "speakers of an initiating action can deploy prolonged hold phases in order to keep the action open and to urge for a responsive action from the recipient" and suggests that these intermediate positions exist

[37] The portion of the study presented in this section was published as a book chapter (see Fogarty-Bourget, Artemeva, & Fox, 2019).

along a continuum ranging from “stage” to “home” (rest), thus allowing speakers to weaken or strengthen their claim of speakership: the closer the suspension occurs to the stage area, the stronger the claim over speakership; the closer the suspension occurs to home, the weaker the claim over speakership (p. 19). This observation implies that hands occupying a rest position convey a surrendering or yielding of speakership. Cibulka, however, does not focus on rest positions *per se*.

In one of the few studies that do focus on rest positions, Sacks and Schegloff (2002) observe that generally, gesturing hands return to the same rest position from which they depart. The researchers refer to a “moving home position”, which occurs when the hand (or hands) performs small, often repetitive movements (or moves digits), either with or without an object, further referred to as fidget, and returns to fidgeting after each gestural excursion. In these cases, although the hand is in motion, it is nonetheless occupying a rest position (i.e., it is not involved in gesturing) (p.138). Some researchers characterize rest positions as lacking in movement and hand tenseness (Bressem & Ladewig, 2011; Ladewig & Bressem, 2013), while others describe certain rest positions in which hand tenseness is present (e.g., Dosso & Whishaw, 2012; Sacks & Schegloff, 2002).

Few studies mention that gestural rest positions have a capacity to convey communicative meaning. Those studies that do, tend to highlight rest positions as the indicators of the property of non-speakership (not being in the role of speaker) or speech conclusion. For example, Dosso and Whishaw (2012) suggest that rest positions can be indicative of what a speaker may do next, such as intent to continue or discontinue speakership. Andrén’s (2012) research also indicates that body movement combined with the semantics and timing of speech often makes action completion "intersubjectively manifest" (p. 160). Although Andrén focuses on bodily actions that involve the handling of physical objects and not on rest positions, his study suggests that rest positions can be used in an expressive and meaningful way, a phenomenon that requires further research. In my research on gestural rest positions in chalk talk lecturing (Fogarty-Bourget, 2016, 2017; Fogarty-Bourget, Artemeva & Fox, 2019), I have observed that just as a speaking subject can exercise speech-act silence (cf. Huckin, 2002 for its equivalent in writing) (see Chapter 2, Section 2.4.2) while continuing to gesture, a gesturing subject can exercise gestural silence (Fogarty-Bourget, 2016, 2017; Fogarty-Bourget, Artemeva, & Fox, 2019) through stillness or non-gesturing, while continuing to produce speech, facial expressions, and other movements.

In order to control for teaching medium, I selected a sub-corpus of five video recordings of four IPs in Group B (see Chapter 5, Section 5.3.2) teaching in North American universities (IP9, IP12, IP13, and IP14) with chalk and chalkboard. This portion of the analysis was carried out using QMTA (as described in Chapter 5, Section 5.6.2), however, in this case, data were uploaded into NVivo 10 (QSR International, 2012) and the parts of the video recordings with the instructors holding their hands still (and not involved in a movement excursion) were demarcated and transcribed before descriptive coding was applied to lower-level and then higher-level actions (Norris, 2004, 2011). The application and grouping of descriptive codes formed the basis of a coding tree. The developed coding tree was applied by two researchers independently to selected video excerpts. Outcomes were reached by consensus.

The analysis revealed typified and recurrent patterns of the IPs' use of gestural silences and co-occurring speech acts (cf. Austin, 1975; Bavelas et al., 2002), speech-act silences (Huckin, 2002), and body configurations, which work together with other verbal and nonverbal behaviours to construct meaning (e.g., Andrén, 2012; Cibulka, 2015). The findings suggest that mathematics instructors use some ensembles (Kendon, 2004) of gestural silence as devices (Hyland, 2001, 2005) to involve students in doing mathematics by inviting their public contributions in the lecture; for example, some devices are used to demonstrate instructors' attentive listening as an invitation to students to provide a response to a question (cf. Jaworski & Sachdev, 1998; Rowe, 1986). An example of how the IPs in this study use gestural silence to make evident their action of attentive listening is provided in Figure 24.

24*A*	24*B*
	
[interrogative] "What's the first step when I have an actual value*?*" [silence] -waiting for student response- [silence] -listening to student response- [non-specific listener response] *nodding* "Yeah"	[interrogative] ("*So, how are you gonna prove this*?") [silence] -waiting for student response- [imperative] "Tell me in one sentence why it's true" [silence] -pause- **"**You can use two, if you need to, but if you can (*do it in one*)" [silence] –waiting for student response- [explanation] ("*I keep telling you folks, don't try to find a proof. Understand why it's true and then write down that understanding*") [non-specific listener response] ("*Yeah*") [silence] -listening to student response-

Figure 24. IPs using gestural silence in the wrist-grip position to make evident the action of attentive listening. 24A. IP posing a question to the students. 24B. IP issuing a question followed by a command. Both instructors maintain the position while waiting for, and listening to, student responses.

Figure 24A depicts an IP who, after having written a line of text on the board, has turned to the students and, gripping her right wrist with the left hand, has brought both hands to rest in front of her in a wrist-grip position as she poses a question to the students. She holds her hands this way as she scans the classroom, awaiting responses. After a few moments, a student responds, and the IP maintains her position as she listens to the response. When it becomes evident that the response is correct, the IP begins to nod her head in agreement with the student but does not move her hands until the student has fully articulated the response.

The analysis suggests that the IPs considered in this study take up the wrist-grip position when attempting to engage students in a discussion of what has been written on the chalkboard. The position is often paired with a question or command, or used when pausing the commentary to ensure that the students have understood the content (checking). The IPs typically maintain the wrist-grip position while waiting for students to respond and listening to the students' responses, and use the position, in coordination with such speech acts as directives and interrogatives and/or speech-act silences, to create gestural silences whose function is to indicate the change of their role from IPs doing mathematics and providing explanations to IPs as listeners. This change appears to signal to students that the IP expects a response and invites them to participate by demonstrating that the IP is prepared to listen. For example, the IP in Figure 24A uses the wrist-grip position to communicate to the students her role as attentive listener by coordinating the position with an interrogative, maintaining the position silently while both waiting for and listening to the response, and pairing the position with head nodding. As previously mentioned (Chapter 2, Section 2.4.2), non-specific listener responses, including head nodding, are used to convey attentiveness (cf. Bavelas et al., 2002). Figure 24B provides another example of an IP using the wrist-grip position in much the same way as the IP in Figure 24A: the IP asks a question, assumes the wrist-grip position, and silently waits for students to respond. When no students come forward, he issues a command to the students ("tell me in one sentence why it's true") while maintaining the wrist-grip position. When there is no response from the students, he provides some further explanation (a "hint") and then resumes the position. Once a student does respond, the IP maintains the position while listening to the response.

Figure 25 presents a position that appears to be shaped by the actions involved in the embodied performance of chalk talk; for example, the instructor's action of writing on the chalkboard or pointing at students to prompt a response. The position appears to be used to involve students in doing mathematics by allowing them to participate in what the instructor has written on the chalkboard.

25A	*25B*	*25C*
		
(*points at student with open hand*) *returns to rest position* [silence] -listening to student response- [clarification] “Sorry?” [silence] -listening to student response-	*turns from chalkboard to face students* *scans classroom* [silence] -waiting for student response/checking-	[clarification] (“*So this is what you*”) *turns from chalkboard to students* “*should memorize*” *scans classroom* [silence] -listening to student question-

Figure 25. IPs using gestural silence in the fist held high position to involve students in what has been written on the chalkboard. 25A. IP prompting students to complete the statement he has written on the chalkboard. 25B and 25C. IP has finished writing on the chalkboard and retracted the hand used for writing into the rest position while turning to face the students.

Figure 25A presents an IP prompting students to complete the statement he has written on the chalkboard. He points at a student with an open hand, then retracts it, adopting the rest position of a fist held high. His hand remains resting while he listens to the students’ responses. When it becomes clear to him that no student has the correct answer, the IP moves his hand from the rest position in order to explain the problem further. Figures

25B and 25C depict two other IPs who have finished writing on the chalkboard and retracted the hand used for writing into the rest position while turning to face the students. Figure 25B shows the IP after he has explained mathematical content, gesturing with an open hand at the chalkboard; when finished explaining, he retracts his hand into a fist and turns to face the students with his hand still held up. He maintains the position as he scans the room for questions or comments (checking). Observing none, he continues with the explanation. In much the same way, the IP presented in Figure 25C finishes writing on the board, retracts his hand, and turns to the students while maintaining the rest position. He provides brief metacommentary about what he has written on the board, while fidgeting with the chalk in his fingers (a “moving home position” [Sacks & Schegloff, 2002, p. 139]). He then scans the class (checking) for questions or comments. A student interjects and the IP maintains the rest position while listening. Once the student has concluded, the IP moves his hand from the rest position to articulate a response. The position was observed in all video-recordings of IPs in the sub-corpus, consistently used as a device to involve students in doing mathematics. This finding speaks to the typified and recurrent nature of gestures and gestural silences as a feature of the chalk talk umbrella genre.

In terms of meaning construction, these positions closely resemble the provisional home positions (Cibulka, 2015) that span across speaker turns “to keep the action open and to urge for a responsive action from the recipient” (p. 19). The IPs use gestural silence to involve the students in a discussion about what has been written on the chalkboard. The stillness of the IPs' hands creates a temporal opening, or "window[38]," for students to publicly participate (i.e., take up turns at talk) by raising their hands or interjecting. These windows close when the IPs break the gestural silence. Figures 25B and 25C suggest that the communicative function of a combination of hand stillness and body orientation (turning from chalkboard to the students) is used to acknowledge the students as discourse participants in the discussion of what has been written on the board by signaling to them that they are free to comment. In other words, the listeners can work out the illocutionary force of the silence based on the situational context (cf. Huckin's [2002] discussion of speech-act silences in written texts).

This portion of the analysis suggests that, within the context of chalk talk, typified and recurrent gestural silences employed by instructors have a particular situational

[38] According to Scollon, mediated actions occur "in a social space" (p. 4) defined as the *site of engagement* (Scollon, 1998, 2001), which is a concept that describes where, when, and how actions occur. Scollon (2001) views a mediated action as "a unique moment in history" interpreted in real-time through a lens of the social practices to which it is linked (p. 4). The site of engagement is the "window opened" through an "intersection of social practices and mediational means" that make the action the "focal point of attention of the social actors" involved (p. 4). Scollon's work has been influential to scholars who inform my theoretical framework (e.g., Norris, 2004, 2011), and thus is not unrelated to my understanding of social practice, however, I use the idea of "opening a window" differently to describe a specific rhetorical strategy synonymous to creating a space to take up a turn at talk (Sacks, Schegloff, & Jefferson, 1974) or obvious opportunity to participate (see Paoletti et al., 2018).

importance. The performance of chalk talk requires near continuous movement of instructors' hands as they write on the board and provide metacommentary on what they have written (see Fox & Artemeva, 2012). The gestural rest positions with the hands remaining relatively close to the gesturing stage (cf. Cibulka, 2015) or to the chalkboard allow the IPs to create gestural silences during which they can briefly switch from doing mathematics to attending to students, while keeping the hands available for gesturing and writing. Furthermore, because the performance of the chalk talk umbrella genre requires mathematics instructors to be highly active, alternating between writing on the board and concurrently articulating what is being written, turning to the students, providing metacommentary about what has been written on the board, moving, pacing, gesturing, and so on (Artemeva & Fox, 2011), the points in the lecture when the IP's hands are held still stand out as deliberate and expressive communicative actions (cf. Kendon, 2004). In other words, the study indicates that through the stillness of their hands, mathematicians create what Acheson (2008) calls communicative "events" (p. 542) in which the shift from doing mathematics to involving the students in doing mathematics becomes palpable. There are instances, however, when simply creating a window for students to respond does not present sufficient motivation for students to publicly participate in doing mathematics. In such cases, the IPs use alternative strategies to encourage or even apply pressure on students to respond. Alternative strategies used by the IPs to involve students in doing mathematics are presented in the next subsection.

9.2.3 Encouraging students' responses and public participation in doing mathematics

In my previous research (Fogarty-Bourget, 2013), I observed that instructors use a variety of strategies during chalk talk lectures to encourage students to publicly participate in doing mathematics including issuing commands, providing further explanation (or "hints"), and using repetition of speech and gestures to urge students to respond. In addition to these strategies, the IPs in the present study used instances of high modal intensity, proxemics, and theatrics to actively involve students in doing mathematics and encourage their public participation.

The first three examples[39] show how an IP uses instances of high modal intensity to elicit participation from the students in the classroom with the intention to involve them in publicly doing mathematics. Figure 26 shows an instance in which the IP has just posed a question to the students ("so which one is max and which one is min*?*"). The IP turns to the students and awaits a response. As he waits, he stands with his hands at his sides without speaking or moving his body; in this moment, the only movements he makes are shifts in his gaze as he looks back and forth across the room at the students seated in the lecture hall in a pan-gaze.

[39] The analysis was conducted in the same way as described in Section 9.1.2 (see pp. 188-189).

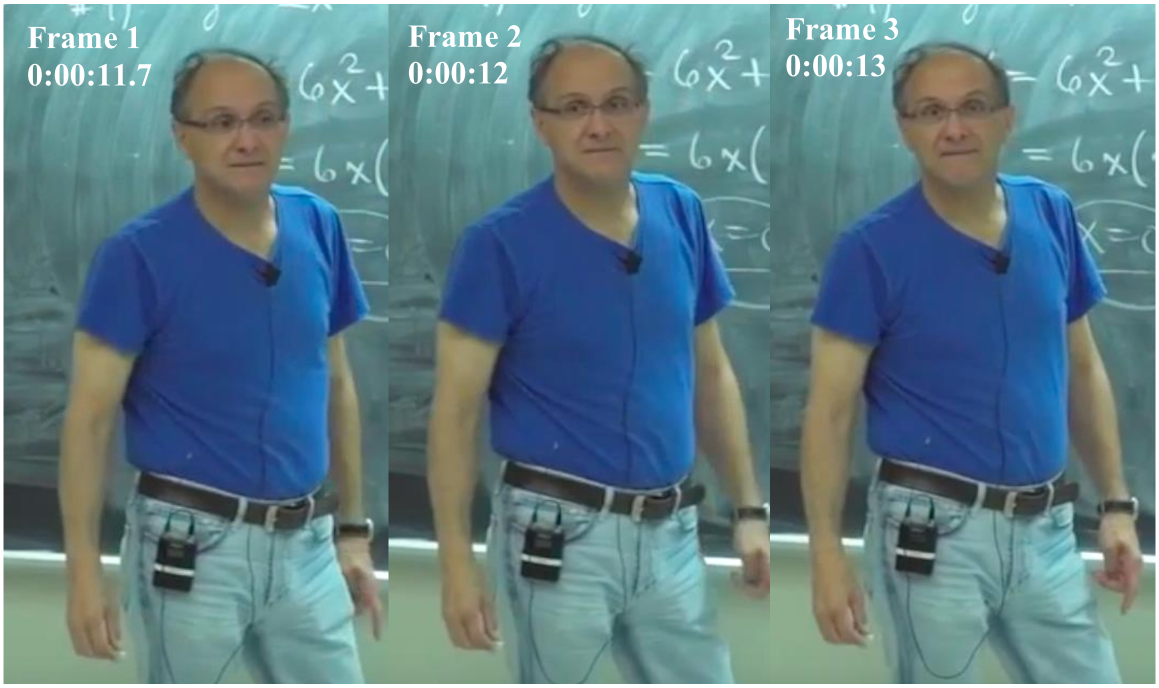


Figure 26. An example of an IP using gaze with high modal intensity (occurring as a result of distributional scarcity) to elicit participation from the students seated in the classroom.

In this example the mode of gaze takes on high modal intensity (i.e., it stands out as attention-catching). This is in part because, as mentioned previously (Section 9.2.2), in the context of chalk talk, instructors are moving almost constantly. Further, because this way of teaching involves articulating what is being written, and then turning to face the students to talk about what has been written (Artemeva & Fox, 2011; Fox & Artemeva, 2012), university mathematics instructors spend much of the lecture speaking. Between writing (and articulating) mathematical notation, explaining content to students, interacting with students, and managing the classroom, instances in which instructors stand silently facing the students are distributionally scarce (i.e., rare), and therefore, stand out as particularly salient communicative events (Fogarty-Bourget, Artemeva, & Fox, 2019). During data collection, I observed that when instructors stop speaking but are still writing on the chalkboard, the students can hear the sounds of the chalk on the board and continue to take notes, however, when the chalk also stops, a particular silence is created which causes the students to look up from their notes (see also MacKenzie & Barany, 2014 on the ongoing sequence of words and board-sounds [p. 16]). Even beyond the university mathematics lecture hall, it has been observed that in various classroom contexts (see Jaworski & Sachdev, 1998), teachers' silence is *marked* (Trubetzkoy, 1936; see also Andersen, 2001) and used to capture and focus students' attention (Jaworski & Sachdev, 1998, p. 277). In the example above (Figure 26), the higher-level action of the IP's prolonged stillness, (total) silence, and bodily orientation are notable and, therefore, attract students' attention. Throughout this pragmatically salient moment, the only changes occurring in the IP's positioning are his shifts in gaze. Because in this instance all other modes remain constant (i.e., unchanging), the IP's shifts in gaze stand out as prominent lower-level actions. That is, the mode of gaze in this context can be perceived as markedly more *intense* than earlier interactions which typically involve speech, gesture, and/or writing in addition to shifts in gaze (see for instance, Section 9.1.2, Figure 17). Once the IP has captured the students' attention, he attempts to evoke a response (Figure 27). To encourage students to respond to the question he has just posed, he intensifies his gaze by widening his eyes and raising his eyebrows while tightening his lips together. In doing so, he manipulates the appearance of his facial display, namely the size of his eye and brow area (larger) and mouth (smaller).

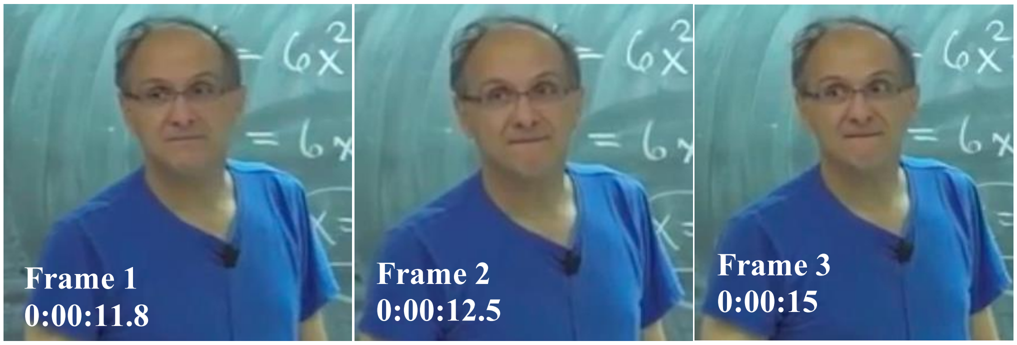


Figure 27. An example an IP using facial display with high modal intensity to encourage students in the classroom to respond.

After posing a question ("*which one is max and which one is min?*") (see Section 9.1.2, Figure 17), the IP turns to face the students. Initially, he gazes around the room with his eyebrows slightly raised, and his lips pressed shut, however, his facial expression is fairly relaxed (Figure 27, Frame 1). Not being met with a response, he continues to look around the room expectantly; he widens his eyes, raises his eyebrows higher, and purses his lips more tightly together (Frame 2). By pursing his mouth shut, the IP demonstrates his silence to students. By minimizing the size of his mouth while widening his eyes and raising his eyebrows, his inquisitive gaze appears larger and more intense. Finally, the IP fixes his gaze on a student who looks as though they may have a response to the question. To encourage the student to respond, he focuses his gaze on the student, and exaggerates his expression by widening his eyes, raising his eyebrows, and tightening his mouth further (Frame 3). After a moment, the student offers a muffled response. The IP uses these changes in facial display to encourage the students in the classroom to respond to the question. By maintaining his focused gaze with a high degree of modal intensity and demonstrating his unwillingness to resume his turn at talk (emphasized by his tightly closed mouth), he is applying a degree of pressure on the student(s) to take up a turn at talk and thus become actively involved and publicly participate in the problem-solving process (see Fogarty-Bourget, Artemeva, & Fox, 2019).

The next example (Figure 28) shows how gesture can be used with a high degree of modal intensity to encourage students' public participation in the classroom. Cooperrider (2017) draws on notions stemming from markedness theory by making a distinction between foreground and background gestures, where foreground gestures appear to have heightened communicative intent and background gestures "are a kind of unmarked default against which foreground gestures *stand out*" (p. 191; emphasis added). The framework offers four hallmarks of foreground status, any one of which is sufficient to qualify a gesture as foregrounded. These hallmarks are as follows: the gesture is 1) used concurrently with a spoken demonstrative (e.g., *this*, *that*, *these*); 2) produced in absence of speech, or sequentially with speech (i.e., speech trails off before production of the gesture, or resumes after the gesture is produced); 3) co-organized with speaker gaze (i.e., the speaker looks at the gesture or in the direction being indicated by the gesture); and/or 4) produced with a visible degree of effort made evident by the size (larger gestures require greater effort) and precision of the action.

The example in Figure 28 shows the IP making an attempt to clarify the student's muffled response (see previous example). He uses a foreground gesture to encourage the student to elaborate and become more actively involved in the problem-solving process.

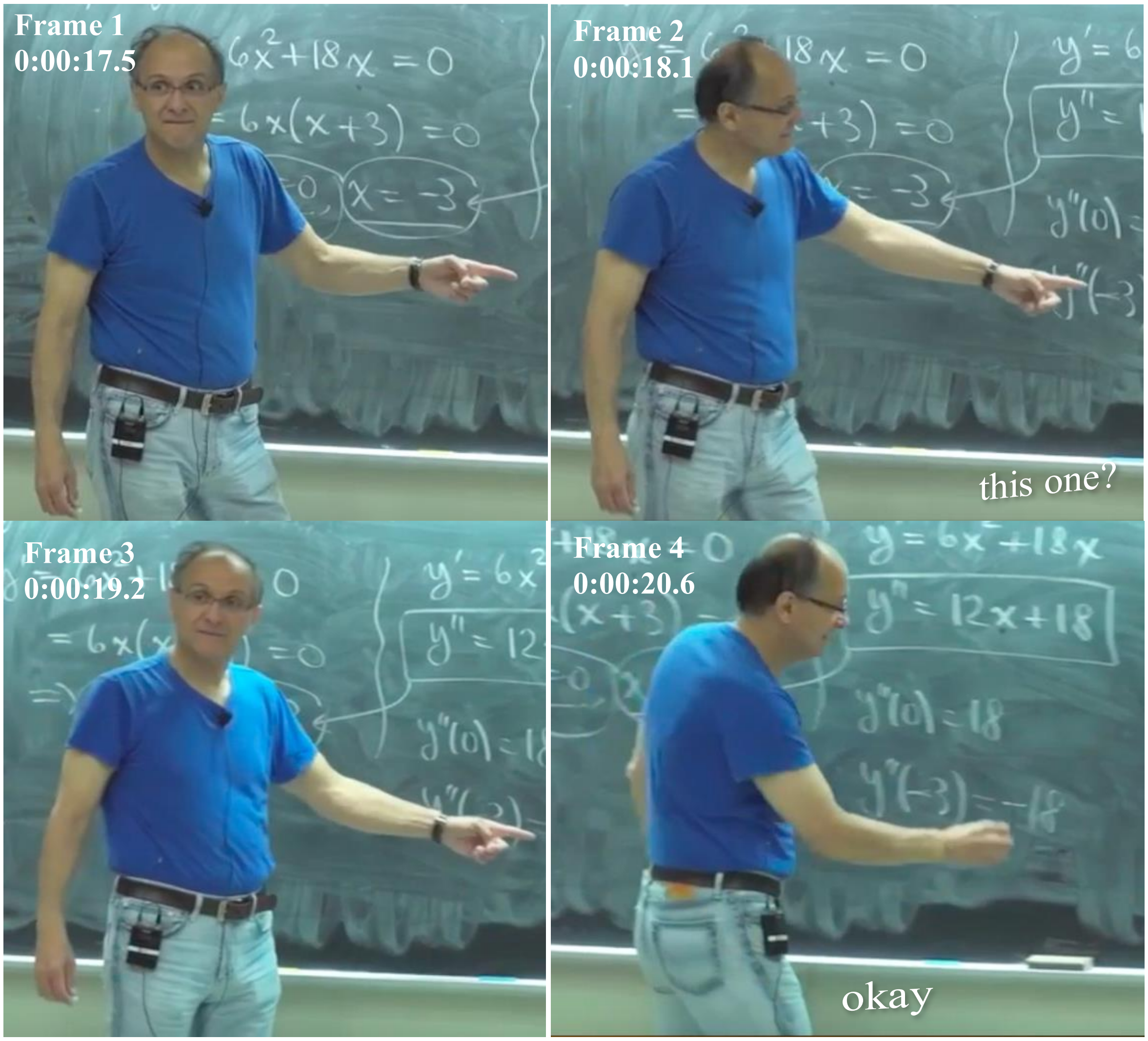


Figure 28. A foreground gesture being used to encourage a student's active involvement in problem-solving.

After the student first utters the response, the IP maintains his gaze (eyes wide, eyebrows raised) directed at the student and without speaking produces a pointing (deictic) gesture (Figure 28, Frame 1). The IP holds this position for a moment, then simultaneously looks toward the board and extends his index finger further in the direction of his gaze. Then, following his gaze, he takes a step toward the chalkboard with his index finger still extended (Frame 2) and poses a clarification question to the student ("*this one?*"). After asking the question, he directs his gaze back at the student, still holding his index finger toward the board, and waits for the student to respond (Frame 3). Once the student confirms their response, the IP agrees with the student ("*okay*") and steps toward the chalkboard to write the answer (Frame 4). The IP's pointing gesture (Frames 1-3) meets all four hallmarks of foreground status (Cooperrider, 2017): it is

- used concurrently with a demonstrative ("*<u>this</u> one?*")
- produced sequentially with speech (beginning before and ending after the utterance)
- co-organized with gaze (the IP looks in the direction being indicated); and
- produced with a visible degree of effort (made evident by the duration of the gesture, additional extension of the arm, and step in the direction being indicated).

In the excerpt of data used for this portion of the analysis (see Section 9.1.2, p. 188-189), the IP produces a number of gestures, however, the gesture described above (Figure 28) stands out as a "critical part" of the IP's message (Cooperrider, 2017, p. 176). Unlike other background gestures that the IP uses (see for instance Section 9.1.2, Figure 17, Frame 3), this instance of pointing is produced in such a way that it is in the foreground of the speaker's and listener's awareness and in the foreground of the interaction (p. 181). In other words, the gesture is produced using a high degree of modal intensity; it is employed with greater strength (Pirini, 2014, p. 83) or emphasis (Norris, 2016) than other background gestures produced earlier in the interaction, and used to focus the attention (Norris, 2004) of students in the classroom. As has been noted (Bavelas, 1994; Cibulka, 2015), when a gesture is held for an extended period of time, as the IP's pointing gesture is, it becomes a kinetically held question or request for a response from the addressee. The IP uses this gesture, in coordination with gaze, speech, movement, and facial display, to encourage the student to elaborate. The qualitative features that make the gesture stand out, or become foregrounded, contribute to high modal intensity which helps to focus and maintain student attention and involvement in the subject matter.

As discussed in Chapter 8 (Section 8.1), one IP in my study had to use a variety of classroom management strategies because many of the students in her class were inattentive and/or noisy during the lecture. The IP used the mode of proxemics (Hall, 1963) (i.e., the measured distance between people) with varying degrees of intensity as a strategy to encourage students' active involvement and participation in doing mathematics. Specifically, she would move closer to the students seated in the classroom at specific points in the lecture. The IP was teaching the lecture using a DCP and microphone, meaning she was seated at a desk behind a podium, writing mathematical notation with a pen on a piece of paper projected on to two large screens at the front of an auditorium that seats approximately 230 students (see Figure 29).

Figure 29. A photograph of the lecture hall used at the time of the recording.

The lecture hall was also equipped with three large chalkboards (see Figure 29) which were illuminated, however, the lecture hall itself was dimly lit during the lecture so that the projector screens were more visible. The first row of seats was closest to the podium, on the same floor level at the IP; the students seated in the first row were attentive and regularly participated. The majority of the students were seated in tiered rows in the centre of the lecture hall and towards the back. Past the first few rows of seating, it was predominantly the large screens (which showed the IPs writing of the mathematical notation including her hands) that were plainly visible while the IP appeared very small seated behind the podium and in the low-lighting of the hall her facial features were not visible. When she sat behind the podium doing mathematics, a number of students in the classroom would begin chatting with each other and would appear to disengage from the focused interaction of the lecture. As a strategy to involve students in doing mathematics, she would actively shift from doing mathematics with her head down (see Figure 30) to focusing her attention on the students seated in the classroom by peering over the podium and removing her glasses and/or standing up and looking around the room (see Figure 31).

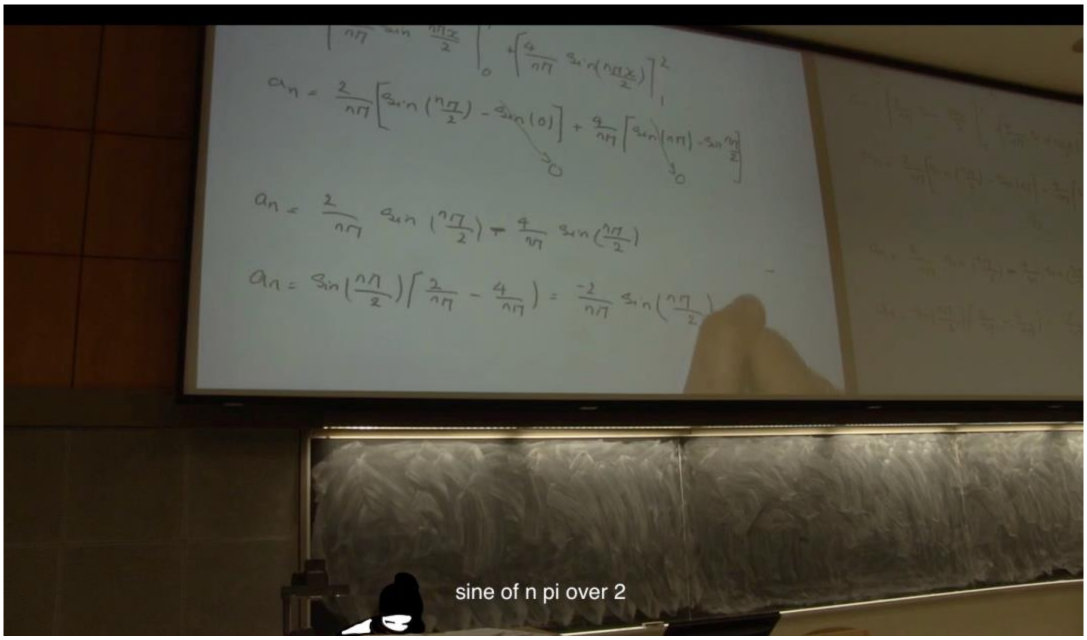


Figure 30. An IP doing mathematics using a DCP mounted on a podium.

Figure 30 shows the IP seated at the desk behind the podium doing mathematics under the DCP and providing commentary. Her head is down but her voice is audible and her hand and the mathematical notation she is writing is visible. As she writes she provides commentary “sine of n π over 2”. After concluding the line of notation, she poses a question to the students “now what can I do with sine of n π over 2?”. As she poses the question, she begins to stand up to provide metacommentary (Figure 31).

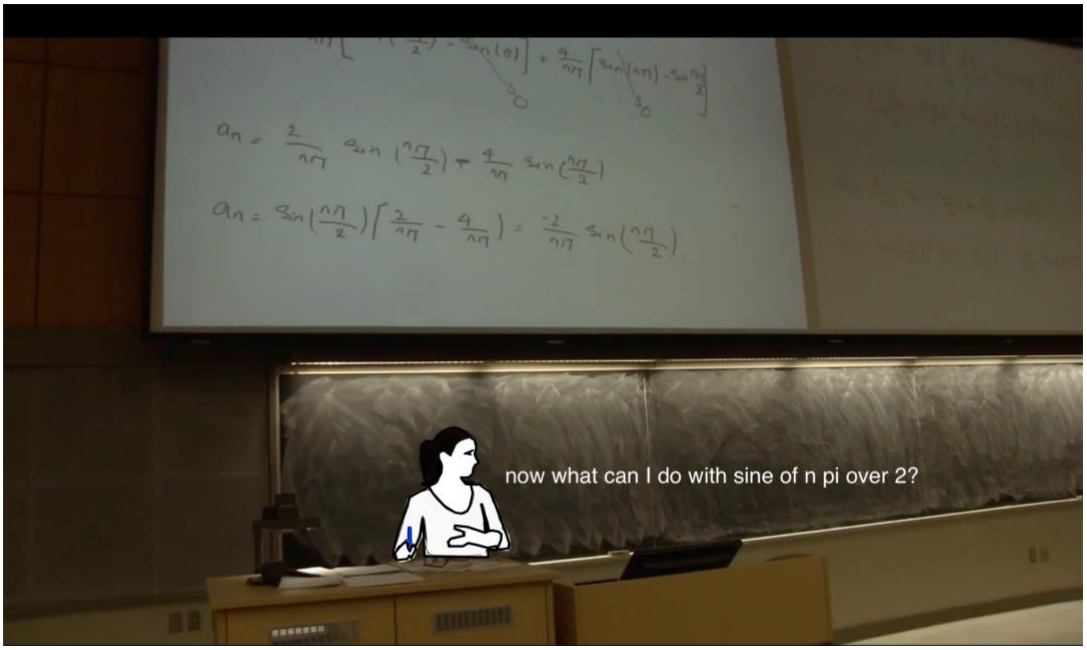


Figure 31. An IP standing up behind the podium to pose a question to the students seated in the hall.

Throughout the lecture, the IP would shift between doing mathematics and providing commentary while seated behind the podium and standing up to discuss the mathematics (provide metacommentary) and ask questions to the students. By standing up and making herself more visible and available to move closer to the students the mode of proxemics becomes slightly more intensified (see Norris, 2004, pp. 19-20), as does the mode of gaze. From my classroom observations, I noted that when the IP stood up from the podium, the students seated in the middle and the back of the lecture hall would stop chatting and refocus their attention, however, whether seated or standing, the IP was seldom able to elicit public participation from the students while she was positioned behind the podium. In order to encourage students to publicly participate in doing mathematics (i.e., contribute responses to mathematical questions) she would walk out from behind the podium, towards the students seated in the lecture hall, and pose questions to the students while standing up against the first row of desks[40] (see Figure 32).

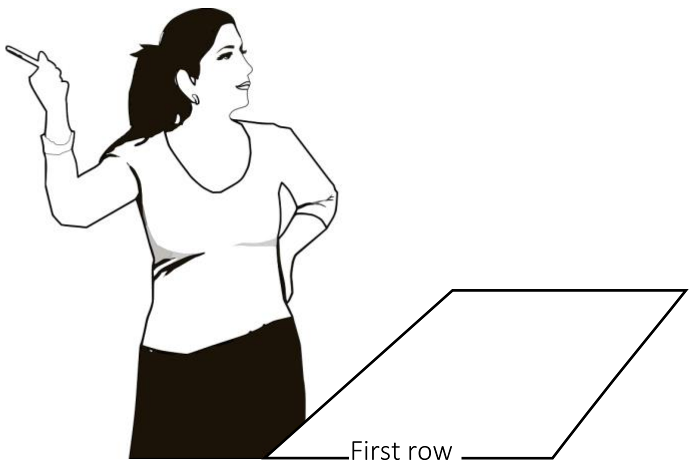


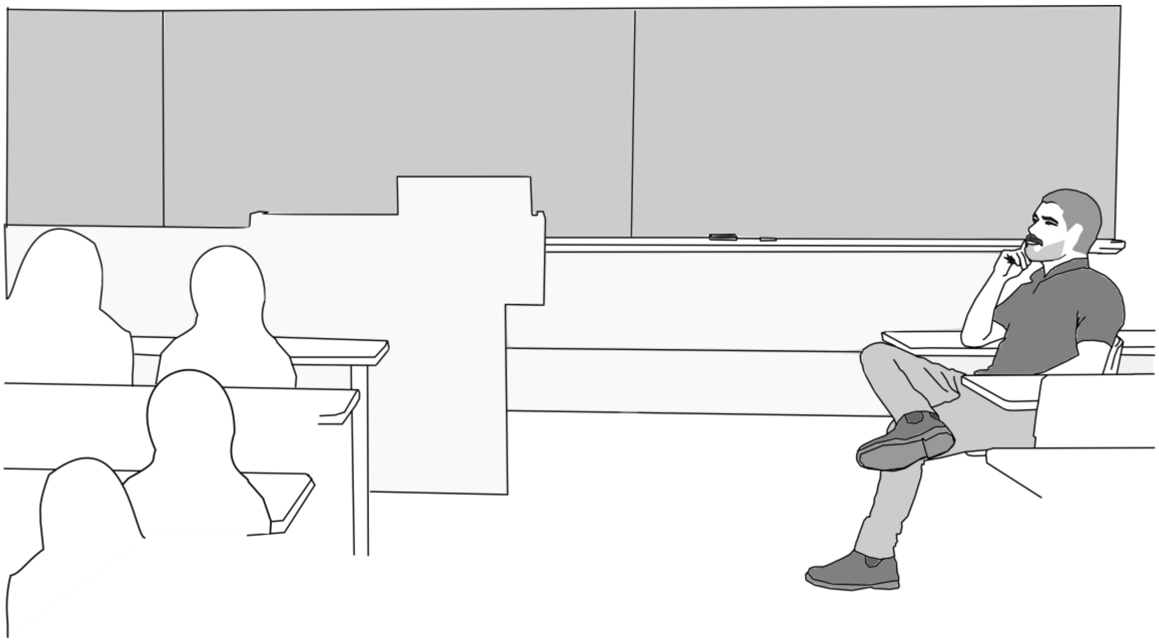
Figure 32. An example of an IP using proximity to students to encourage their participation in doing mathematics.

A few moments after posing a question to the students and standing up behind the podium, the IP walked in front of the podium and towards the first row of desks where she proceeded to pose questions to the students seated beyond the front row of the lecture hall. Figure 32 shows a line drawing of the IP attempting to solicit contributions from the students by positioning herself against the first row of desks and gazing in the direction of the students seated in the middle and back rows of the lecture hall. As Beebe (1980) notes, instructors' use of proxemics can have an impact on students' participation in the

[40] The image presented in Figure 32 is an example of the IP using the strategy of approaching the first row of desks to encourage students to publicly participate in the lecture. In this example a line drawing is used to depict the IP because students were present in the screenshot and were edited out of the data.

classroom in part because closer personal distance between instructor and student is generally interpreted by students as increased concern and/or interest from the instructor (p. 20). Reducing the proxemic distance between the instructor and students has been shown to increase the likelihood of student activity and involvement and can be used as a strategy to increase engagement when it appears as if students have lost interest in a problem (see Podkowińska, 2018, p. 442). The IP in the next example also incorporated the use of proxemics into his strategies for encouraging participation in the classroom, however, he did so in a much more exaggerated way.

At the time of observation, the IP in this example was lecturing in a small classroom with a capacity of approximately 35 students. The course he was teaching was scheduled in an evening time slot of the summer semester and students regularly missed classes. Often, there were only a few students attending the lectures and those that did required a lot of encouragement to respond to questions. During the lecture, the IP would use many strategies to urge the students to publicly participate in doing mathematics. One such strategy was to perform theatrics wherein he would sit down at a desk and appeal to the students in the classroom to continue doing the mathematics for him (see Figure 33).



"Now, I have forgotten everything I know *pause* so you must tell me what to do next *sits down in front row* you must tell me exactly because I've lost all my knowledge but I don't want to stop the lecture *pause* what time is the lecture over? *checks time* Oh you have plenty of time to advise me what do we do here?"

Figure 33. An example of an IP using theatrics to put pressure on students to participate in doing mathematics publicly in the classroom.

The line drawing in Figure 33 depicts an instance where the IP has just gone through several problem-solving sequences within which he used a number of the strategies presented thus far (e.g., asking questions, providing wait-time, looking around the room and gesturing to students) with little result. After writing a problem on the chalkboard, the IP turns to the students seated in the classroom and says "Now, I have forgotten everything I know *pause* so you must tell me what to do next". He then walks towards the students and sits down in the front row and says "you must tell me exactly because I've lost all my knowledge but I don't want to stop the lecture". Next, he checks the time "what time is the lecture over?" and concludes "oh you have plenty of time to advise me what do we do here?" and leans back slightly and crosses one leg over the other to show that he will wait. After a moment, a student makes an attempt and the IP springs up and starts to solve the problem together with the students providing lots of encouragement as he does. By excusing himself briefly from the role of expert by 'forgetting everything he knows' he puts the onus on the students to publicly participate in doing mathematics and thus applies some pressure on the students to generate knowledge and develop the mathematical narrative (cf. Chi & Wylie, 2014; Paoletti et al., 2018). Variations of this "taking a seat" strategy were used by the IP several times throughout the lecture each with slightly different aims. For example:

> So I'll give you a couple of minutes to digest this knowledge before I move on to the next one *sits down in front row* so if you have any questions fire away no problem no problem at all *leans back in seat* so I give you a couple of minutes we are in no rush there is no haste.

In this case, rather than putting pressure on the students to contribute to advancing the mathematical narrative, the IP takes a seat in the same relaxed manner to halt the mathematical narrative giving them time to actively involve themselves in thinking through the mathematics, formulate questions, and "digest" the knowledge.

The findings presented in this chapter break new ground in understanding student engagement from a teaching perspective and the teaching of mathematics at the post-secondary level. The rhetorical strategies presented here are not well represented in existing research literature on university mathematics teaching (cf. Malmstrom &

Eriksson, 2018; Yoon et al., 2011). And, while particularly rich or illustrative examples were selected for this discussion, they are very much representative of the teaching practices I observed throughout this innovative research. The IPs in my study, though not all equally theatrical, jocose, or even confident in their teaching, were invested in students' learning and engagement, not as a "catch-phrase or slogan" (McMahon & Portelli, 2004, p. 60) or ingredient for achievement (cf. Finn & Zimmer, 2012; Fredricks et al., 2004), but in the very practical sense of shared involvement in learning and collaborative action in the classroom. The implications of this research are discussed in the next chapter (Chapter 10) as are the limitations and future directions for study.

Chapter 10: Conclusion

With this chapter I conclude the dissertation by reflecting on the research study and discussing avenues for future inquiry. First, I present a summary of the study and its key findings. The summary is followed by a discussion of the study's limitations and implications for research and pedagogy. In the final section of the chapter, I discuss directions for future research.

The study investigates the phenomenon of student engagement in university mathematics lectures from the instructors' perspective by using a theoretical and analytical framework that combines concepts from discourse and genre studies (Bakhtin, 1986; Devitt, 1993; Hyland, 2001; Miller, 1984, 2015; Swales, 1990), Vygotskian sociocultural theory (Vygotsky, 1987), situated learning (e.g., Lave & Wenger, 1991; Rogoff, 1990), multimodality (Norris, 2004, 2011, 2013; Räisänen, 2015), speech theory (Austin, 1975; Bavelas, Coates, & Johnson, 2002; Huckin, 2002), and gesture studies (e.g., Andrén, 2012; Cibulka, 2015; Kendon, 2004; Ladewig & Bressem, 2011), and draws on the literature on student engagement (e.g., Dewey, 1938; McMahon & Portelli, 2004; Pianta et al., 2012), education (e.g., Bernad-Mechó & Fortanet-Gómez, 2019; Scanlon et al., 2007; Wubbels & Brekelmans, 2005), and mathematics teaching (Mason, 2000; Querol-Julián & Arteaga-Martínez, 2019; Rodd, 2003; Sfard, 2014). Specifically, the study seeks to understand what constitutes student engagement in the university mathematics teaching context and develop a context-specific definition of the construct of student engagement that serves as a precursor to identifying and analysing the strategies instructors use to help facilitate engagement in undergraduate mathematics lectures. In addition to the original research questions, the question, "What aspects of the undergraduate mathematics lecture classroom context may impact student engagement?" emerged from the research.

To seek answers to these questions, I conducted a multiphase, mixed-methods study with an explanatory sequential design, conducted from a pragmatic perspective (Creswell & Plano Clark, 2011) wherein the results of an initial, mixed methods phase of data collection and analysis (Phase 1) were used to respond to the first research question and inform a second, qualitative phase (Phase 2). The results of the two phases were merged and interpretations were drawn to respond to the remaining questions. Multiple types of data were gathered throughout the data collection period, including student surveys, two-part instructor interviews, video recordings of university mathematics lectures, and observational field notes. The data were analysed using quantitative methods (surveys) and qualitative methods including QMTA and rhetorical move analysis (Swales, 1990; see also Hyon, 2018). The study allowed me to develop a deeper understanding of student engagement as it is realized in university mathematics lectures, and of the teaching practices used by university mathematics instructors to help facilitate student engagement in this context.

In response to the first research question (What constitutes student engagement in the university mathematics teaching (chalk talk) context? How can it be defined?) the analysis has revealed that students' focused attention, involvement, and participation in jointly doing mathematics in the classroom constitutes student engagement in chalk talk lectures. Thus, student engagement in university mathematics lectures is defined as a state of sustained mutual activity wherein the students and instructor cooperate towards accomplishing the shared task of doing mathematics. Student behaviours that instructors view as indicative of student engagement in the mathematics lecture context include gaze directionality focused on the instructor, the writing on the board, or students' notes, facial displays that convey active listening and/or understanding (i.e., thinking involvement), and verbal or nonverbal forms of participation in the lecture (i.e., nodding, asking and answering questions, and contributing to the mathematical narrative being written on the board).

In response to the second research question (What aspects of the chalk talk classroom context are influential to student engagement? What aspects can facilitate student engagement in this context? What can make student engagement difficult?), the findings indicate that the learning environment and classroom climate are influential to student engagement in the chalk talk lecture classroom context. Within the learning environment, teaching styles that promote frequent student-instructor interaction and smaller class sizes can facilitate student engagement, whereas excessively large lecture halls, time constraints, and students' use of electronic devices in the classroom can be barriers to student engagement. In regard to classroom climate, instructor behaviours that convey teacher immediacy and cultivate positive student-instructor relationships appear to facilitate student engagement. These include interactions that make students feel supported, respected, and that generate a warm and welcoming classroom atmosphere. In contrast, instructor behaviours or aspects of the learning environment that make it difficult for students to understand the course content (for example, messy or disorganized writing, inaudible speech) and/or which generate a cold or negative classroom atmosphere such as student-instructor interactions which cause students to feel ignored, disliked, or isolated can impede student engagement. Teaching technologies such as DCPs and penTPCs may address some environmental challenges (e.g., improving visibility for students seated in large lecture halls, faster delivery to accommodate condensed curriculums) but also appear to limit the degree to which instructors can interact with students using eye contact, facial display, gestures, and physical proximity. More research needs to be conducted to investigate how such teaching technologies shape student-instructor interactions in the university lecture classroom and the impact they may have on student engagement in university teaching contexts.

Finally, in response to the third research question (What strategies do university mathematics instructors use to help realize student engagement in chalk talk lectures?), the multimodal analysis revealed that the IPs in my study used a variety of multimodal rhetorical strategies to help realize student engagement in chalk talk lecturers. These included strategies to establish and maintain a focused interaction with the students in the classroom by including the students as discourse participants in the lecture and capturing and maintaining students' attention as the lecture unfolds. Instructors also facilitate student engagement through involving students in jointly doing mathematics by strategically asking questions, focusing students' attention, and ensuring students are following along in the construction of the mathematical narrative (e.g., issuing checking questions, using strategic board choreography and annotation techniques). Finally, instructors help to facilitate student engagement in the classroom by encouraging students' public participation and soliciting student contributions to advance the mathematical narrative that is being written on the board. Instructors' strategies for soliciting student participation in the classroom include indicating the need for a response (e.g., by posing a question in speech and writing, turning to the students, and looking at the students), creating a window for students to respond (e.g., by using instances of gestural silence and wait-time [Rowe, 1986]), and, when necessary, applying pressure on students to respond (e.g., by using instance of high modal intensity [Norris, 2004, 2011], physical proximity, and theatrics).

Building off the work of Artemeva and Fox (2010, 2011; Fox & Artemeva, 2012), I view chalk talk as an umbrella genre overarching a cluster, or set, of subgenres (cf. Devitt, 1991; see also Bazerman, 1994; Smart, 1999) enacted by practitioners to teach university mathematics to undergraduate students. Viewing chalk talk from this perspective makes evident instructors' behaviours and practices that have become typified and recurrent across local, institutional, and global contexts. Of these typified and recurrent behaviours, question-posing emerges as a pillar of university mathematics teaching practice (cf. Paoletti et al., 2018; Mason, 2000; Speer, 2008; Viirman, 2015), used as "the strategy of dialogic involvement par excellence" (cf. Hyland, 2001, p. 569). The IPs in my study use rhetorical and "funneling" questions for focusing attention and involving students in the process of doing mathematics (Mason, 2000; see also Viirman, 2015, p. 1179) and checking questions to gauge students' attention and ensure they are following along (Speer et al., 2010; Viirman, 2015). Importantly, after transitioning from "opening the lecture" to "doing mathematics" the lectures themselves are structured by a series of cyclical question-posing routines to scaffold/fade (cf. Mason, 2000) student through doing mathematics and "lead students to their guess" (IP2). In this way, contrary to what some scholars have suggested (e.g., Gerofsky, 2010; Malmstrom & Eriksson; Paoletti et al., 2018; Yusof & Tall, 1998), much of mathematics teaching at the university level involves heavily scaffolded, guided participation (Rogoff, 1990; see also Mason, 2000; Sfard, 2014; Speer, 2008). This finding lends support to the observation made by previous researchers of university mathematics teaching that chalk talk lecturing is, in fact, a highly interactive style of teaching (e.g., Fogarty-Bourget, 2013; Fogarty-Bourget Artemeva, & Fox, 2019; Mason, 2000; Speer, 2008).

Using a holistic, multimodal analytical approach (Norris, 2004, 2011, 2013; Räisänen, 2015) to inform my investigation of student engagement in undergraduate mathematics lectures, has allowed me to consider contextual features (e.g., aspects of the learning environment and broader classroom context, discourse communities, and global trends) as well as the micro features of interaction that make up the teaching of a chalk talk lecture (e.g., multimodal utterances [Kendon, 2004] or parts of utterances such individual gesture phases [see Bressem & Ladewig, 2013; Ladewig & Bressem, 2011]), as well as the ways in which objects and the environment shape such interactions, including tools and technologies that are enabling to the performance of a lecture, and those that are constraining (cf. Norris, 2004, 2011, 2013; Räisänen, 2015; Schryer, 1993). While a holistic approach to inquiry places certain limitations on the amount of data that can be reasonably analysed by a single researcher (limitations of the study are discussed further in Section 10.2), the outcomes provide a "thick description" (Geertz, 2008, p. 312) , offering on one hand, detailed descriptions of the phenomena of interest that are reflective of the spatial-temporal context(s) in which they are situated (see Räisänen, 2015), and a myriad of avenues for discovery and rich program for research on the other (directions for future research are presented in Section 10.3). The implications of this research are discussed in the next section.

10.1 Implications for Research and Pedagogy

The research presented in this dissertation comprises an original contribution to existing literature on student engagement and university mathematics teaching. It provides a perspective on student engagement from the teaching point of view. A number of significant findings are highlighted, including the tremendous complexity of student-instructor interactions that take place in the chalk talk classroom, and the highly interactive nature and co-actedness of student engagement in this context, as well as the impact of various teaching technologies on the teaching practices of instructors. These findings, and the study overall have important implications for research on human interaction, university teaching, and student engagement from both teaching and learning perspectives. As well, by shedding light on the ways in which instructors interact simultaneously with the writing on the board and students in the classroom, this research makes an important contribution to the study of written discourse as multimodal embodied practice. By adopting a holistic approach to inquiry, this research demonstrates the value of multimodal analysis for identifying and describing the subtle or nuanced features involved in face-to-face teaching and for understanding the potential impact of contextual features such as objects and the environment on classroom interactions. In this dissertation I have attempted to provide detailed and step-by-step descriptions of the analytical procedures used in the study. In doing so, I hope to provide a guide for analysts interested in conducting fine-grained, multimodal analyses with or without the support of coding software. I have also attempted to draw attention to the importance of developing understandings of student engagement that are context-specific which have important implications for future empirical research of the construct. Researchers seeking to understand more about student engagement may benefit from narrowing their scope to a specific context and, from there, developing a definition of engagement that is appropriate for that context before attempting to identify and measure what is seldom defined (cf. Wang et al., 2016).

In addition to implications for research, the study also has pedagogical implications which appear particularly important at this time. A recurrent theme throughout the research has been that of time and pacing. For students, the pacing of the lesson and speed of delivering content play an important role in their engagement in lectures (see Bergsten, 2010); so too are students' perceptions of the amount of time that instructors can provide to interact with them and to answer questions and address their concerns and uncertainties (see Gasiewski et al., 2012; Scanlon et al., 2007; Bryson & Hand, 2007). For instructors, teaching to large numbers of students in vast lecture halls amounts to less time to interact with individual students and difficulties connecting with students seated beyond the first few rows of desks. Additionally, universities offering courses with condensed curricula leave instructors looking for ways to deliver more content faster. Essentially, despite the vast institutional interest in promoting student engagement (e.g., Dunne & Owen, 2013; NSSE, 2019), the seemingly pervasive trend in post-secondary education of over-extending instructor resources (see Exeter et al., 2010) wherein instructors are "having to work within the constraints of diminishing time and resources" (Croft & Ward, 2001, p, 197) has created a recipe for hindering student engagement in core undergraduate mathematics lectures, where research has suggested student engagement is most critical (e.g., Gasiewski et al., 2012). Often, new teaching technologies such as DCPs, penTPCs and forums for online or distance education are proposed as a means of mitigating such challenges (see Bullock et al., 2002; Exeter et al., 2010; Maclaren et al., 2018); however, they may come at a cost to instructional quality and student engagement itself. A common criticism of chalk talk lecturing has been that instructors speak “at a faster pace than the students can write” (Lew et al., 2016, p. 25), while the majority of qualitative analyses of university mathematics teaching practice have shown that instructors prefer the chalk talk method because it “gives the students time to write accurately what is written on the board” (Iannone & Miller, 2019, p. 5), and “slows the lecturer down and makes it therefore easier for the listener to follow the argument” (Greiffenhagen, 2014, p. 521). It has also been noted that “unlike the marks in books, papers, or slides, blackboard inscriptions can only ever unfold at the pace of chalk sliding against slate. The intrinsic necessity of bit-by-bit unfolding in mathematical exposition is thus built into chalk as its means of writing”, and therefore, “blackboard writing forces the sequential coordination of depiction and explanation at the board, pacing and focusing speaker and audience alike” (Barany & MacKenzie, 2014, pp. 14-15). Being that there is agreement that speed and pacing are important influencers on student engagement (e.g., Bergsten, 2012; Lew et al., 2016; Querol-Julián & Arteaga-Martínez, 2019) and significant awareness that board writing necessitates material to be presented at a moderate pace, it does not seem to follow that the introduction of teaching technologies that even marginally speed up the delivery of material or impose layers of interpersonal distance between the instructor and students may facilitate student engagement. Although such observations may seem evident, there does not appear to be much discussion surrounding the potentially problematic impact of these proposed changes to teaching university mathematics reflected in the available research literature.

Finally, based on my observations presented here and elsewhere (Fogarty-Bourget, 2013, 2017), it appears that the use of some strategies for facilitating student engagement in university mathematics lectures may be related to the instructor's level of teaching experience (see also Auerbach et al., 2018; Wubbels & Brekelmans, 2005). These include the ways in which instructors portray themselves to students (i.e., as a masterful instructor), relate to, and interact with the students, particularly, in terms of demonstrating behaviours associated with teacher immediacy (i.e., facing the students, making eye contact, being patient) (cf. Bergsten, 2012; Furlich & Dwyer, 2007). This finding has implications for the development and implementation of training materials for new teaching staff and faculty.

10.2 Limitations of the Study

There are a number of limitations to the study, namely, in terms of its size and scope. First, the study is limited to English-speaking universities in three countries. As Artemeva and Fox's (2010, 2011; Fox & Artemeva, 2012) and research demonstrates, chalk talk is a typified and recurrent way of teaching undergraduate mathematics used by the global community of university mathematics instructors; future research may include the recruitment of student and instructor participants of university mathematics courses taught in different countries and different languages around the globe (see also Maclaren et al., 2018; Viirman, 2014, 2014). Such research promises to reveal more about the nature of student engagement as it is realized in different cultural contexts. For instance, Artemeva and Fox (2011) observed cultural differences in classroom interactions and a difference in gender roles in terms of students' participation in the classroom, with one instructor participant noting that in Canada, he found it more difficult to engage female students in the conversation during the lecture regardless of their proficiency in mathematics, which he identified as a North American phenomenon (pp. 365-366).

Second, the study is limited by the participant sample size. The study includes a small sample of instructor participants, the majority of whom are experienced, award-winning instructors who are highly proficient speakers of English. Due to the multimodal nature of this research study, novice instructors were reluctant to participate in the study citing apprehension to be observed and video recorded despite assurances that they would not be evaluated on the quality of their teaching. Because mathematics departments are diverse and characterized by "extraordinary cultural and linguistic diversity" (see Artemeva & Fox, 2011, p. 3), a larger sample of participants including a wider range of teaching experience and cultural diversity would be more reflective of university mathematics teaching faculty around the globe. While the study included a sufficient sample of SRs for this type of study, a larger student sample would strengthen the study and make it possible to observe statistically significant correlations between students' demographic data and their responses to Likert items. Further, expanding the student sample to include upper-year students and students majoring in science, technology, and mathematics, as well as engineering, would provide more insight into student engagement in university mathematics lectures across STEM disciplines. More insight could also be provided by adjusting the open-ended questions in Section C of the student survey to prompt more narrative accounts from the student perspective. The open-ended questions were phrased in such a way that limited the types of experiences that SRs could reflect on (e.g. *If you have had an experience with a "very good" mathematics lecturer,* *what kind of things did they do that you liked?*). An even more open-ended phrasing of the questions (e.g. *Tell me about a time when an instructor's teaching stood out to you as "very good"*) may have prompted a wider range of responses.

Third, the video data used in the study include recordings of lectures where the camera is trained only on the instructors. As well, qualitative data (video recordings, interviews, and field notes) were collected from IPs while the data collected from SRs were limited to the student survey portion of the study. This means that the study investigated student engagement in chalk talk lecture contexts primarily from a teaching perspective. Incorporating video data of the students seated in the classroom and interview or focus group data with student participants would add more depth of perspective about student engagement in lectures and student-instructor interactions that take place in the classroom from a learning perspective.

Finally, the study was conducted by a single investigator (myself) (with only one other coder involved to calculate inter-coder reliability on a limited set of data). The fine-grained nature of the qualitative multimodal analysis limited the amount of data that could be analysed by a single researcher. Future research would benefit from involving a team of analysts to analyse more data and offer a variety of perspectives. In particular, while I have approached the study from a discourse studies perspective and incorporated the views of the instructor participants into the final narrative, future research including analytical perspectives from the mathematics domain would offer increased insight into the teaching practices of instructors of chalk talk lecturing. Directions for future research are discussed further in the next section.

10.3 Directions for Future Research

The study reported on in this dissertation revealed multiple avenues for inquiry which promise to contribute to a rich program for research. Throughout data collection and analysis, I observed many patterns of behaviour that recurred across different local and geographical contexts, many of which lay beyond the scope of this dissertation. The study shed light on the multimodal discursive strategies used by instructors of university mathematics to help facilitate student engagement in undergraduate mathematics lectures including strategies to encourage students' public participation in doing mathematics in the classroom. The next step in this research is to investigate the strategies instructors use to respond to students' public attempts at doing mathematics (see Fogarty-Bourget & Artemeva, 2018).

In addition to recurrent and typified behaviours used in the enactment of chalk talk (cf. Artemeva & Fox 2010, 2011; Fox & Artemeva, 2012), as mentioned in this study and elsewhere (e.g., Fogarty-Bourget, 2013), I have observed subtle differences in the ways that the novice and experienced instructors interact with students in the classroom. Directions for future research include larger-scale comparative analyses of the teaching practices used by highly experienced university mathematics instructors and novice instructors in their first years of teaching. Investigating the role that teaching experience may play in shaping student-instructor interactions may help explain why some undergraduate mathematics lectures are perceived by students as engaging, while others seem to "miss the mark" (Fox & Artemeva, 2012, p. 97).

My doctoral research has shed light on a few of the ways that the use of technology in the classroom can impact student engagement and shape student-instructor interaction in undergraduate mathematics lectures. These observations reveal several avenues for research that appear pressing. One such avenue is to investigate students' use of electronic devices (namely smartphones and laptops) in the classroom to understand more about how students use these devices during class time and their use during lectures may impact student engagement and instructors' ability to "read the room". A second direction for future research related to the use of technology in the lecture classroom is to investigate the use of various teaching technologies as principal mediums for delivering lectures. As mentioned, the differences that emerged from the comparative analysis (Chapter 8, Section 8.3) were too extensive to describe in this dissertation and many lay outside the research objectives of the study. This finding in itself speaks to the need for more research on the ways that teaching technologies shape the teaching practices of university lecturers and student-instructor interactions that take place in the classroom. Relatedly, given the inherently interactive nature of student engagement in the university mathematics teaching context, there is a need for research of online university mathematics teaching and the potential impact of online learning on student engagement.

Finally, like Hyland's (2001, 2005) research of audience engagement in written academic genres, my study has revealed disciplinary specific discursive patterns and behaviours associated with student engagement in university mathematics lectures. Future research in university teaching in other disciplines and instructors' strategies for facilitating student engagement in other cultural and disciplinary contexts will no doubt reveal further insights about the nature of student engagement at the post-secondary level.

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Appendix A: Student Survey

Section A: Demographic information

Age: ____________________________

Gender: __________________________

First language: ____________________

Language spoken at home: ________

Additional language(s): ___________

____

Have you been schooled in languages other than English? Yes / No

If yes, please list the language(s) and the level of schooling: ___________________

Previous schooling (e.g., High school):

____

Current year of study: __________________

Average grade: ________________________

Percentage of classes attended: __________

Do you excel in mathematics? Yes / No

Mathematics course(s) attended in the 2015/2016 academic year: ______________

Engineering stream: ___________________

Professional aspiration:

____

Section B: In your opinion, a good mathematics lecturer:

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly Disagree
1) Speaks clearly	1	2	3	4	5
2) Checks to make sure students grasp the material	1	2	3	4	5
3) Asks questions	1	2	3	4	5
4) Is encouraging	1	2	3	4	5
5) Is an expert in the field	1	2	3	4	5
6) Writes neatly and clearly on the chalkboard	1	2	3	4	5
7) Uses new technology in the classroom	1	2	3	4	5
8) Is excited about the material	1	2	3	4	5
9) Grades easily	1	2	3	4	5

10) Allows time to take notes	1	2	3	4	5
11) Relates to being a student	1	2	3	4	5
12) Encourages collaboration in the lecture classroom	1	2	3	4	5
13) Is friendly	1	2	3	4	5
14) Provides real-world examples	1	2	3	4	5
15) Uses physical objects to demonstrate abstract concepts	1	2	3	4	5
16) Faces the students when explaining material	1	2	3	4	5
17) Uses humour in the classroom	1	2	3	4	5
18) Is a full-time, tenured professor	1	2	3	4	5
19) Becomes animated when explaining material	1	2	3	4	5
20) Looks around the room to "check in" with students	1	2	3	4	5
21) Feels there is no question that is too elementary	1	2	3	4	5
22) Is approachable	1	2	3	4	5
23) Is able to explain content clearly	1	2	3	4	5

24) Moves around the room	1	2	3	4	5
25) Describes the "beauty" of math	1	2	3	4	5
26) Is focused mainly on the chalkboard	1	2	3	4	5
27) Dresses professionally	1	2	3	4	5
28) Speaks quickly	1	2	3	4	5
29) Promotes class discussion	1	2	3	4	5
30) Is serious and professional	1	2	3	4	5
31) Organizes group work and discussions	1	2	3	4	5
32) Does not stray from mathematical content	1	2	3	4	5
33) Organizes the chalkboard notes in a way that is easy to follow	1	2	3	4	5
34) Avoids negative evaluation of students	1	2	3	4	5

Section C: Please answer the following questions:

1. If you have had an experience with a "very good" mathematics lecturer, what kind of things did they do that you *liked*?

2. If you have had an experience with a mathematics lecturer that was "not so good", what kind of things did they do that you *did not like*?

If there is any additional information you would like to add, or if you would like to elaborate on your responses or provide feedback on the questionnaire you may do so on the back of this page, or orally to the researcher. Thank you!

Appendix B: Materials for Instructor Interviews

Instructor pre-interview questionnaire

Participant Questionnaire

Participant code (to be completed by researcher):________

Section A: Instructor information

Position: ______________________

Years of teaching experience: _____

Languages spoken:______________

____

Section B: In your opinion, a good university mathematics instructor:

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly Disagree
1) Speaks clearly	1	2	3	4	5
2) Checks to make sure students grasp the material	1	2	3	4	5
3) Poses questions to the students	1	2	3	4	5
4) Is encouraging	1	2	3	4	5
5) Is an expert in the field	1	2	3	4	5
6) Writes neatly and clearly on the chalkboard	1	2	3	4	5
7) Uses new technology in the classroom	1	2	3	4	5
8) Is excited about the material	1	2	3	4	5

9) Grades generously	1	2	3	4	5
10) Allows the students time to take notes	1	2	3	4	5
11) Can relate to the students	1	2	3	4	5
12) Encourages collaboration in the lecture classroom	1	2	3	4	5
13) Is friendly	1	2	3	4	5
14) Provides real-world examples	1	2	3	4	5
15) Uses physical objects to demonstrate abstract concepts	1	2	3	4	5
16) Faces the students when explaining material	1	2	3	4	5
17) Uses humour in the classroom	1	2	3	4	5
18) Is a full-time, tenured professor	1	2	3	4	5
19) Becomes animated when explaining material	1	2	3	4	5
20) Looks around the room to "check in" with students	1	2	3	4	5
21) Feels there is no question that is too elementary	1	2	3	4	5
22) Is approachable	1	2	3	4	5

Participant Questionnaire

23) Is able to explain content clearly	1	2	3	4	5
24) Moves around the room	1	2	3	4	5
25) Describes the "beauty" of math	1	2	3	4	5
26) Is focused mainly on the chalkboard	1	2	3	4	5
27) Dresses professionally	1	2	3	4	5
28) Speaks quickly	1	2	3	4	5
29) Promotes class discussion	1	2	3	4	5
30) Is serious and professional	1	2	3	4	5
31) Organizes group work and discussions	1	2	3	4	5
32) Does not stray from mathematical content	1	2	3	4	5
33) Organizes the chalkboard notes effectively	1	2	3	4	5
34) Avoids negative evaluation of students	1	2	3	4	5

Participant Questionnaire

Section C: Please answer the following questions

1. What do you think are the qualities of a "very good" mathematics lecturer?

2. What do you think are aspects of mathematics lecturing that could sometimes be improved upon?

3. Have you had any experience teaching mathematics courses online? If so, were there certain aspects of online teaching that you liked? Please explain in a few words. Were there certain aspects of online teaching that you didn't like? Please explain in a few words.

If there is any additional information you would like to add, or if you would like to elaborate on your responses/provide feedback on the questionnaire you may do so on this page. Thank you!

Semi-structured interview guide

Interview - Questions and Notes Date:

Instructor code:

1. Where were you educated and in what language?

2. Have you ever taught in other linguistic, cultural, and/or institutional contexts? Did you notice any differences and/or similarities in terms of classroom culture within these contexts?

3. How do you feel about teaching? What do you like about it? What do you dislike, if anything?

4. What do you see as your greatest strength as a university mathematics instructor?

5. Is there any aspect of your teaching that you would like to improve?

6. Do you ever get the sense that some lectures went very well? What gives you that sense? What about lectures that didn't go so well?

7. Do you use the chalkboard in your classes? If so, how do you use it? What do you think about the use of chalkboards in math teaching?

8. Do you use technology in the classroom? If so, what kinds of technology do you use? Are there pros and/or cons to the technology you use in the classroom?

9. Do you prepare lecture notes? and, if so, how do you use them in your teaching?

10. Can you tell if students are following along or if they are lost? If so, how?

11. Can you tell if students are paying attention? If so, how? If a student is not paying attention, do you try to tune them in? If so, how?

12. Do you think it's important to have students participate in the lecture, for example, by answering questions? If so, why? How do you get students to participate/answer questions, if at all?

13. How do you respond to a student who has answered incorrectly?

14. Can you describe how you might handle a classroom in which some students are quite advanced while others may be struggling?

15. Do you have experience teaching at different levels (e.g., first year, third year, graduate students)? What impact does this have on your teaching practices, if at all?

16. Do you have experience teaching students from different disciplinary backgrounds (e.g., ENG, BIO, MATH)? What impact does this have on your teaching practices, if at all?

17. What do you think about teaching online? Do you have any experience teaching online? If so, please you describe your experience?

18. How can you tell that students are engaged and what does it mean to you?

19. Has your teaching style, or the strategies you use changed from when you first started teaching to now? If so, how?

20. If you could provide some piece of advice for new instructors that are about to teach their first course, what would it be?

21. Do you have anything else you would like to add?

Thank you for your time!

Appendix C: Ethics Clearance Forms

Carleton UNIVERSITY
Canada's Capital University

Research Compliance Office
511 Tory | 1125 Colonel By Drive
| Ottawa, Ontario K1S 5B6
613-520-2600 Ext: 2517
ethics@carleton.ca

CERTIFICATION OF INSTITUTIONAL ETHICS APPROVAL

Ethics approval for the following research has been cleared by the Carleton University Research Ethics Board-A (CUREB-A) at Carleton University. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics ID: Project # 104509

Principal Investigator: Chloe Fogarty-Bourget

Co-Investigator(s): **Natalia Artemeva (Primary Investigator)**
Chloe Fogarty-Bourget (Student Research: Ph.D. Student)

Study Title: **Pilot study for "Gestural and discursive strategies for engaging students in mathematical lectures" [Chloe Grace Fogarty-Bourget]**

Effective: **May 17, 2016** Expires: **May 31, 2017**.

<u>Restrictions:</u>

This certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and approved by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

6. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Please email the Ethics Coordinators at ethics@carleton.ca if you have any questions.

APPROVED BY: **Date: May 17, 2016**

Andy Adler, Vice Chair

Carleton University Research Ethics Board-A

Carleton UNIVERSITY
Canada's Capital University

Office of Research Ethics and Compliance
5110 Human Computer Interaction Bldg | 1125 Colonel By Drive
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613-520-2600 Ext: 2517
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CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) at Carleton University has renewed ethics approval for the research project detailed below. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Title: Pilot study for "Gestural and discursive strategies for engaging students in mathematical lectures" [Chloe Grace Fogarty-Bourget]

Protocol #: 104509

Project Team Members: Natalia Artemeva (Primary Investigator)
Chloe Fogarty-Bourget (Student Research: Ph.D. Student)

Department and Institution: Faculty of Arts and Social Sciences\Linguistics and Language Studies (School of), Carleton University

Funding Source (If applicable):

Effective: **May 08, 2017** Expires: **May 31, 2018**.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and cleared by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

6. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

7. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions or if you require a clearance certificate with a signature.

CLEARED BY: **Date: May 08, 2017**

Andy Adler, PhD, Chair, CUREB-A
Shelley Brown, PhD, Vice-Chair, CUREB-A

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The Carleton University Research Ethics Board-A (CUREB-A) at Carleton University has renewed ethics approval for the research project detailed below. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Title: Pilot study for "Gestural and discursive strategies for engaging students in mathematical lectures" [Chloe Grace Fogarty-Bourget]

Protocol #: 104509

Project Team Members: Natalia Artemeva (Primary Investigator)
Chloe Fogarty-Bourget (Student Research: Ph.D. Student)

Department and Institution: Faculty of Arts and Social Sciences\Linguistics and Language Studies (School of), Carleton University

Funding Source (If applicable):

Effective: **May 22, 2018** Expires: **May 31, 2019**.

Please ensure the study clearance number is prominently placed in all recruitment and consent materials: CUREB-A Clearance # 104509.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and cleared by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

6. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

7. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions.

CLEARED BY: **Date: May 22, 2018**

[redacted]

Andy Adler, PhD, Chair, CUREB-A

[redacted]

Bernadette Campbell, PhD, Vice-Chair, CUREB-A

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CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) has granted ethics clearance for the research project described below and research may now proceed.

CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics Protocol Clearance ID: Project # 106363

Project Team Members: Ms. Chloe Fogarty-Bourget (Primary Investigator)
Natalia Artemeva (Research Supervisor)

Project Title: A multimodal investigation of the practices used by university mathematics instructors to engage students in lectures

Funding Source (If applicable):

Effective: **February 22, 2017** Expires: **February 28, 2018**.

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to CUREB-A via a Change to Protocol Form. All changes must be cleared prior to the continuance of the research.
3. An Annual Status Report for the renewal of ethics clearance must be submitted and cleared by the renewal date listed above. Failure to submit the Annual Status Report will result in the closure of the file.If funding is associated, funds will be frozen.
4. A closure request must be sent to CUREB-A when the research is complete or terminated.
5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Please contact the Research Compliance Coordinators, at ethics@carleton.ca, if you have any questions or require a clearance certificate with a signature.

CLEARED BY: **Date: February 22, 2017**

Andy Adler, PhD, Chair, CUREB-A

Shelley Brown, PhD, Vice-Chair, CUREB-A

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CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) has granted ethics clearance for changes to protocol to the research project described below and research may now proceed.

CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Ethics Clearance ID: Project # 106363

Project Team Members: Ms. Chloe Fogarty-Bourget (Primary Investigator)
Natalia Artemeva (Research Supervisor)

Project Title: A multimodal investigation of the practices used by university mathematics instructors to engage students in lectures [Chloe Fogarty-Bourget]

Funding Source (if applicable):

Effective: **October 02, 2017** Expires: **February 28, 2018**

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions or if you require a clearance certificate with a signature.

CLEARED BY: **Date: October 02, 2017**
Andy Adler, PhD, Chair, CUREB-A
Bernadette Campbell, PhD, Vice Chair, CUREB-A

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CERTIFICATION OF INSTITUTIONAL ETHICS CLEARANCE

The Carleton University Research Ethics Board-A (CUREB-A) at Carleton University has renewed ethics approval for the research project detailed below. CUREB-A is constituted and operates in compliance with the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS2).

Title: A multimodal investigation of the practices used by university mathematics instructors to engage students in lectures [Chloe Fogarty-Bourget]

Protocol #: 106363

Project Team Members: Ms. Chloe Fogarty-Bourget (Primary Investigator)
Natalia Artemeva (Research Supervisor)

Department and Institution: Faculty of Arts and Social Sciences\Linguistics and Language Studies (School of), Carleton University

Funding Source (If applicable):

Effective: **March 01, 2018** Expires: **March 31, 2019**

Restrictions:

This certification is subject to the following conditions:

1. Clearance is granted only for the research and purposes described in the application.

2. Any modification to the approved research must be submitted to CUREB-A. All changes must be approved prior to the continuance of the research.

3. An Annual Application for the renewal of ethics clearance must be submitted and cleared by the above date. Failure to submit the Annual Status Report will result in the closure of the file. If funding is associated, funds will be frozen.

4. A closure request must be sent to CUREB-A when the research is complete or terminated.

5. Should any participant suffer adversely from their participation in the project you are required to report the matter to CUREB-A.

6. It is the responsibility of the student to notify their supervisor of any adverse events, changes to their application, or requests to renew/close the protocol.

7. Failure to conduct the research in accordance with the principles of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2nd edition* and the *Carleton University Policies and Procedures for the Ethical Conduct of Research* may result in the suspension or termination of the research project.

Upon reasonable request, it is the policy of CUREB, for cleared protocols, to release the name of the PI, the title of the project, and the date of clearance and any renewal(s).

Please email the Research Compliance Coordinators at ethics@carleton.ca if you have any questions.

CLEARED BY: **Date: March 01, 2018**

[redacted]

Andy Adler, PhD, Chair, CUREB-A

[redacted]

Bernadette Campbell, PhD, Vice-Chair, CUREB-A

Appendix D: Sample of Mixed Selective Transcripts

TOPIC: ENGAGEMENT			
DATA TYPE	TIMESTAMP/ DETAILS	EXCERPT	IP#
INTERVIEW	0:25:50- 0:27:56	Engagement is to narrow the division between lecturer and student, by encouraging participation that gap becomes less clear, we are like one in the teaching/learning process. I just started before you and that's why I grabbed the chalk but I'm also learning you know? I'm also learning a lot from lectures (not just preparing where I see the problem from another angle, fresher angle) and in the classroom, thanks to feedback I also learn, because sometimes students they have no veiled way to look at things and stuff I would think very rigidly about they would think of some fresh approach from another angle that I didn't see, but this can only be achieved if you narrow the gap, because if I keep to myself as lecturer and keep strict separation from students how can I get this feedback that can help everyone, so I think it's good to engage, it's a rough term you know?	IP3
Interview	0:26:50- 0:28:51	What's the point? You're just getting the students to copy down notes- with some students it helps him to copy this stuff down, but it's really better to engage them, right? So	IP6

here's the difference. You copy something down- are you really learning it or you just copying? If you're forced to create it to solve a problem that's feeding forward, that's learning, right? That's a child crawling on the ground, putting their hand on a rock and going ow! and then learning not to do that again. Right? That's feet forward mechanism that's actually the first law of cybernetics. You get more of what you reinforce, right? You get more of well yeah, you get more reinforced, and so I try to use that very actively in the classroom. This is why Socratic method works so well because when you ask them directed questions, you are drawing out the material from them. Now, clearly in math, you can't draw out every complicated formula or differential equation or what have you. But you can draw out the concept the general concepts from them by asking you engage them you get their minds working *forward* on the material rather than just memorizing material rather than just listening to you and trying to remember it, you get them to *create* the lesson, not one hundred percent. I can't do that one hundred percent, but get them to to *feed* forward and to actually <u>use</u> some of what

		you already showed them. . . When you encourage them to ask questions and put up their hand and they ask questions, then you're pretty sure they're engaged.	
Written response	Interview field notes (p.3)	Participation + involvement + attention	IP6
Interview	0:30:48-0:31:29	Engagement for me is when you ask questions, they [the students] try to think of an answer. Sometimes in some class, I said, okay, if you solve this question, you have two minutes to solve it, this is similar to one of the questions in last year's final exam, for example, and you have two minutes to solve it, and they *try* to solve it and give the answer you know? [researcher]they give me some effort? Yeah, to do that.	IP4
Follow-up email	Sat 10/13/2018, 12:11 PM	Yes I think so [can tell they're engaged]. They look at me, they ask questions, they get animated and when they're bored I tell them a story, something that happened to me in the alleys of {CITY} when I was a child. They're all real stories and they have a marvelous effect, as all of a sudden they look at you completely mesmerised as if nothing else existed. One year my students even created a YouTube channel called "ACCOUNTNAME" in which they collected all my stories that year. The channel still exists	IP2

		although I can't edit it as the student doesn't want to give me the password so he's collecting royalties from YouTube I guess. I haven't thought about this much but I would say that engagement is a response, a setting in which the instructor and the class are almost as one. There is a symbiosis going on ... almost everyone is talking about what you're saying.	
Interview	0:26:31- 0:27:17	We it's like well I *laughter* uh I dunno the the the great lectures they tend to be they're rare what is it that happens that? Maybe too many questions maybe students who are *sigh* maybe it's just a hard it's a hard topic and you have to tell stories and that detracts some right? Some don't like it I mean I have to admit some don't like the stories and they'll say you should stick to math I get it in my course evaluations right? And I'll say okay yeah fine but I mean maybe you know everything but some don't right? And the stories helps to to calm you they tend to calm students down cause they can put their pencil down their pen down and and the cellphones come off I mean everybody listens to my stories that's the thing	IP2
Interview	0:31:38-	I think after twenty years,	IP1

	0:33:39	I have got a pretty good sense. And even early on, I dunno I think I’ve really I dunno, I mean, it's just just how do you explain it? It’s just you could see it in their faces- I mean, yes, there's the obvious metrics, like the questions they will ask or not ask. And there will be the, you know, long pauses that you will be faced with after you ask them a question those are the obvious ones. But then but that only you know the interaction is usually with a small fraction of the class and for the other, you know, eighty, ninety percent that sit there don't necessarily interact. You see it in their faces, you really do. And I've seen it. You know, I've sat in on other people's lectures as well. I could see it that as well when the instructor [is] connecting and when they're not. Because they're connecting, the students are engaged. They're actually listening to what you're saying. And if they're not, they're on their laptops checking Facebook. I mean, it's not necessarily all on instructor, but it's, uh it's an indication that maybe they're not, you know, you're not reaching. And that means then you got the tests and the assignments and things like that. I mean, that's

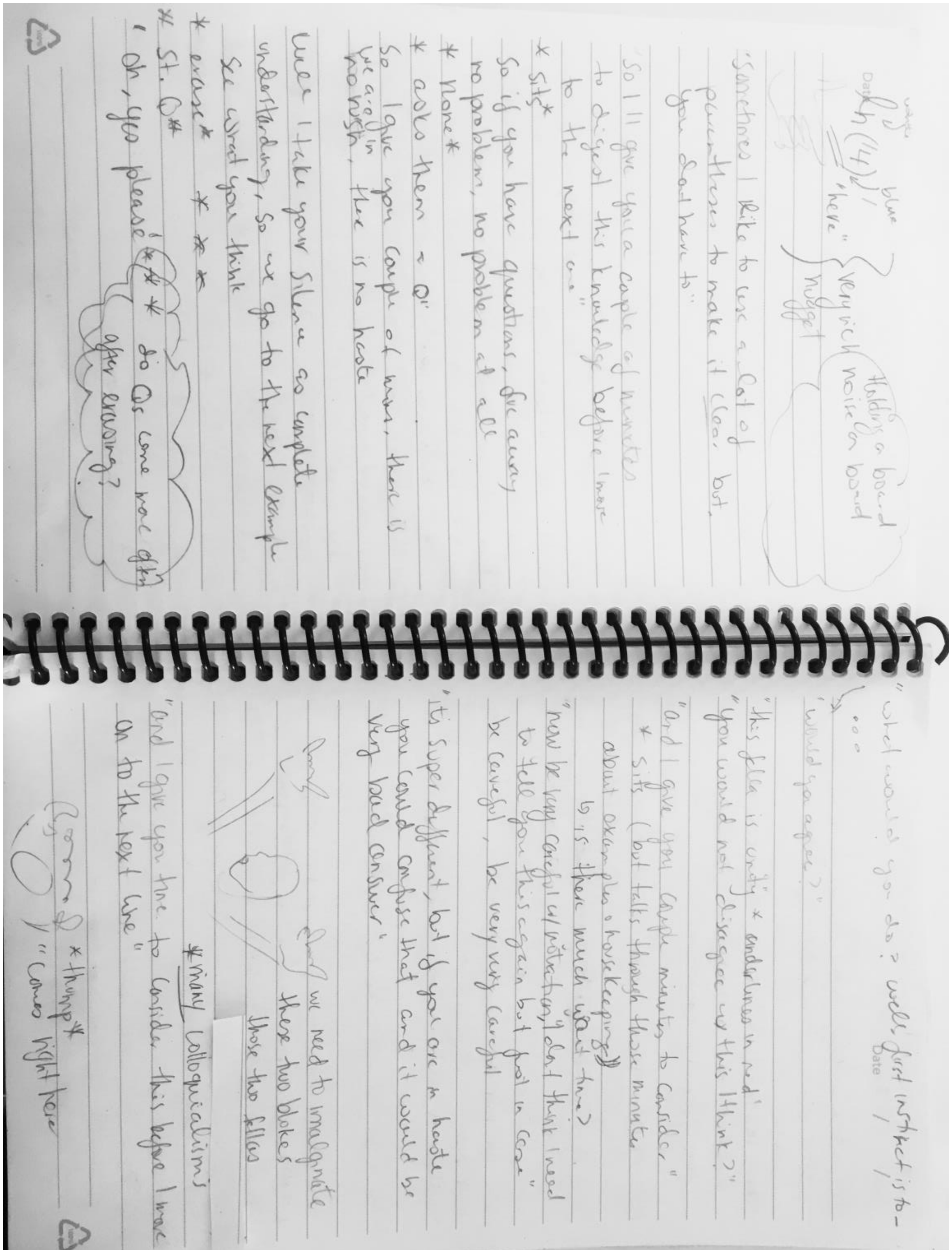
		another obvious metric. You think everybody knows everything, and then you give them that. The test that you think is easy. And everybody, gets, you know, everybody fails, gets a much lower mark that you would expect that's always there. Day of reckoning as well, you know, global sense. But on a day to day basis, locally, you see it in their faces	
Interview	0:58:18-0:59:15	Well, we come back to you know you see it in their faces. Now, what do you looking for in their faces? Eye contact would be a big they're looking at you. They're looking at the board. They're writing in their notes. Um you can see I mean, you know, they're sort of nodding their heads. You say something, you pose the question a rhetorical question. Then you answer it. There's nodding their heads. That shows that they're engaged, of course, asking questions, asking reasonable questions, answering questions that's other evidence that they're engaged, not talking, not staring into their laptops. Not, you know, chattering with their friends. All kind of obvious	IP1
Interview	1:00:05-1:00:32	Yeah I mean, it's almost like when you're having a conversation with somebody and you know that they're not listening to you. You	IP1

		know that their mind is elsewhere. How do you know that? It's just one of those human intuitions that we all have but can’t really explain. And this is just that sort of more, on a bigger level with more eyes sort of pointed in your direction	
Interview	1:09:34-1:10:08	You know, and I'm not impressed with that. Um, but generally, yeah, you look and you look at their- what they're doing has, you know have they got their book opened, have they got their stuff open, have they brought along their printed notes and are mark making marks in them and then yeah- what's what's behind the eyes, right? Anything firing or not?	IP7
Interview	1:10:46-1:11:49	Well, again, Yeah. They’re they are active listeners. You know, they're making notes they’re asking questions, they're they're not static. Their arms are not folded. That's, you know, a bit of a bit of a giveaway, Um, sometimes *chuckles* you know that we do have issues where some students are actively asleep um my, I generally, I'll gently make some sort of snide remark. Um, but when and general, if I can make a joke, the class will laugh and they’ll wake up. But you've got to be a little bit careful, but you want you want them to be.	IP7

		You want them to come and you want. And you you want them to understand the importance, why they're coming. But But we do have. We do, You know, a lot of them they uh their work hours are not normal work hours so they come they're tired. Yeah, so *pause* But yeah so generally it's it's now the question again is do I do that for every student in a in a class over thirty? No. yeah well, you could, you know, you could probably you could probably give it a go to sixty around there you're probably stretching up here.. . . but yeah so I consider a student engaged uh if if they can ask questions, They don't always have to. But, you know, and [researcher] they're ready to Yeah.	
Interview	1:21:29-1:22:28	I think engagement is buying into the keenness and spectacular mind-altering ability that *I* have [researcher] right [IP8] of using statistics in your day to day life. Of things like oh, that's the third ambulance I've seen today *pause* is that statistically significant? or, oh, I've had four punches in three weeks on my bicycle *wondering noises* what distribution is that? Or just just thinking statistically, thinking about probabilities and thinking,	IP8

		oh, what's the probability of winning ten dollars on a scratch card for the lotto? So engagement to me means taking the ideas and using them in the same way roughly the same way that I do doing your thing with them rather than just being exposed to my thing. So that's what engagement means, to me, it means taking, taking the ideas and using them outside the context in which it was taught not just to pass the exam *pause* So I think that's a very high bar for for for engagement	
Interview	1:23:00-1:24:40	[listing examples of student projects] It’s wonderful just - *gesturing excitedly* Yes, I can tell [they’re engaged]	IP8

Appendix E: Sample of Field Notes



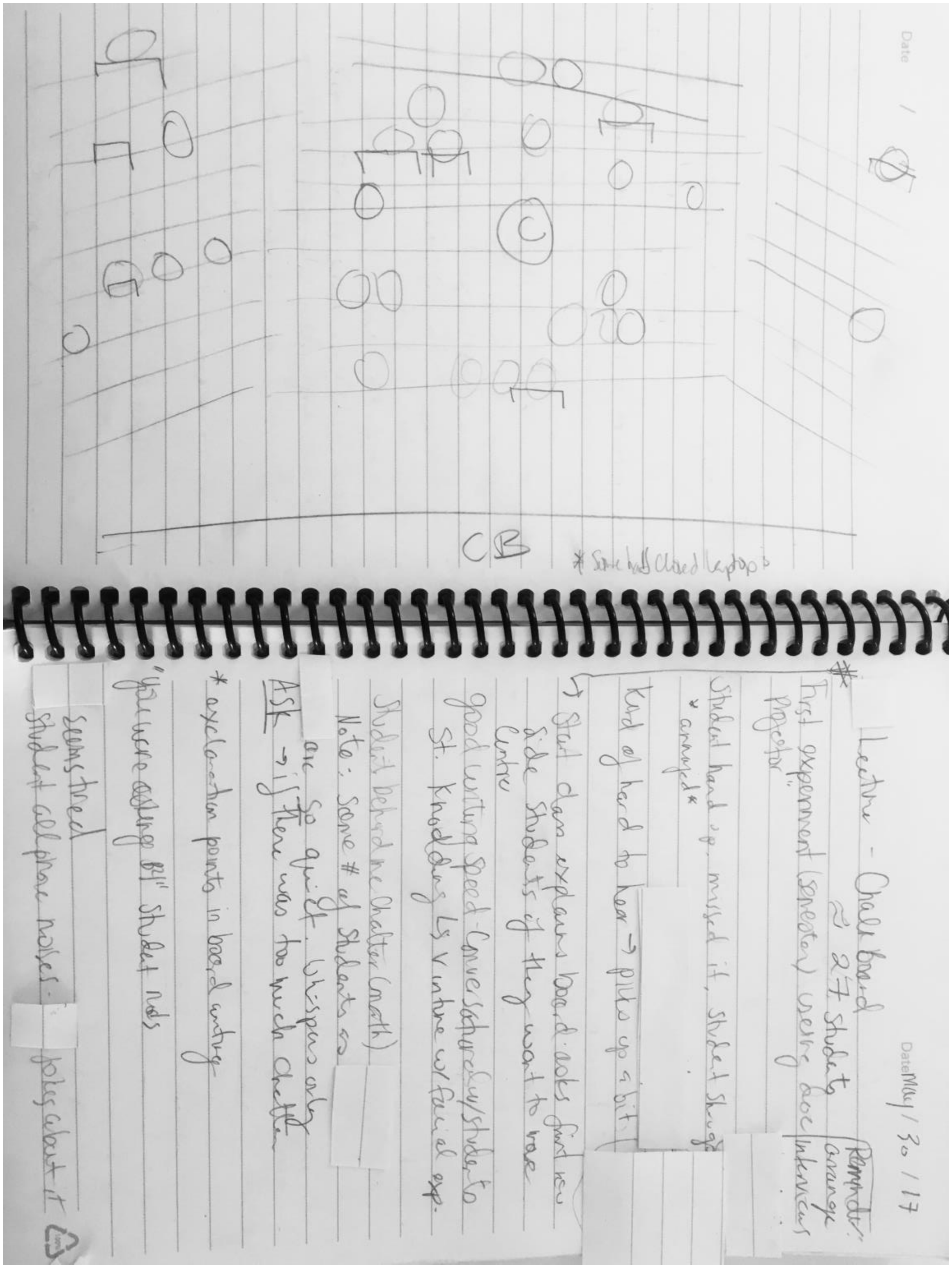


Figure 34. Photographs of field notes collected during Phase 2 of the study.

Appendix F: Samples of NVivo Coding and Coding Tree

Screenshot of textual coding (NVivo 11)

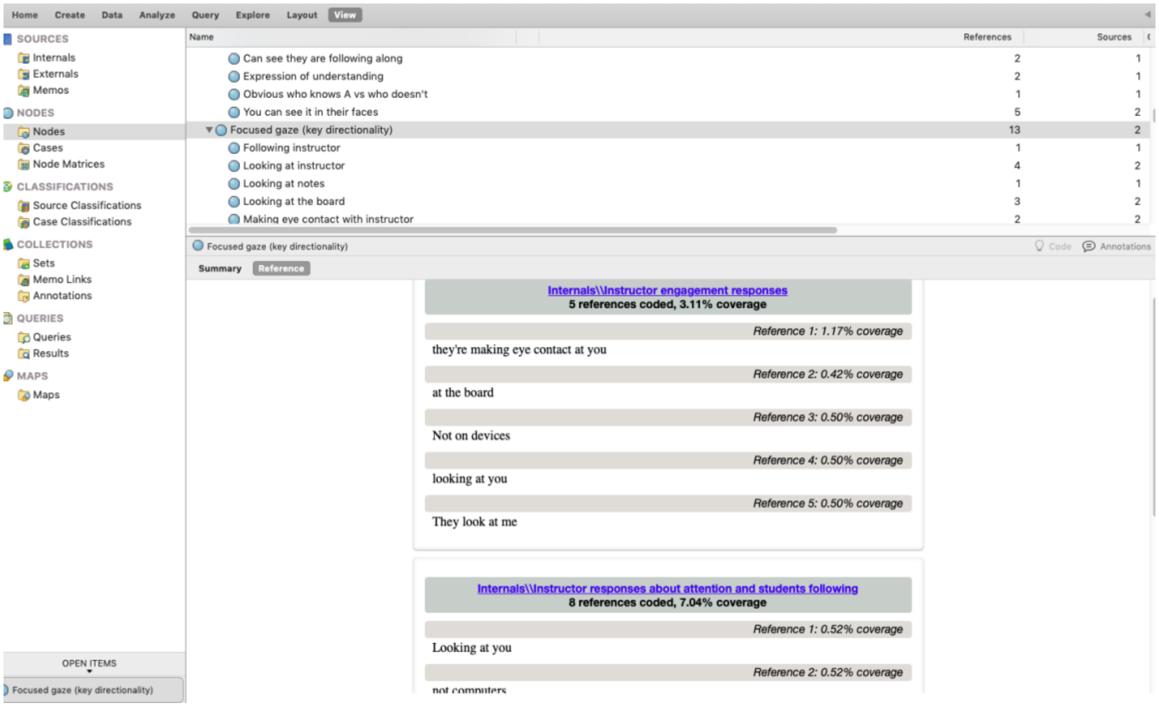


Figure 35. Screenshot of thematic coding tree for textual coding (NVivo 11).

Name	Color	Referen...
▼ DISENGAGED		26
▼ Demonstrating offtrack		9
Agitated		1
Chatting		1
Muttering		1
Not paying attention		1
Puzzled facial expression		3
Tests and assignments as tangible evidence		1
Wrong answers		1
▼ Devices		4
Concern w technology and devices		1
Hard to tell if on facebook or reading		1
Hiding behind electronic device		1
With laptops rapt attention looks the same as blind noteta...		1
Devices as very bad distractions		1
▼ Inactive or absent		4
Blank stare in response to Q		1
Blank stares		1
Stop attending lectures		1
When no one answers		1
Institutional context a challenge to participation		1
▼ Not looking at key players		4
Looking around		1
Looking at devices		1
Looking at phones (obvious)		1
Not looking at the board = not engaged		1
Online components to courses as gateway to being distracte...		1
Time limits inhibits interaction		2
▼ ENGAGEMENT DEFINED		31
▼ Coacting		11
A shared response		1
Context wherein students and instructor are almost one		1
Instructor learning from preparing lectures		1
Instructor's output is students' combined focus		1
It's like having a convo with someone and you know they a...		1
Students and teachers become one in teachinglearning pr...		1
Students are creating the math with the instructor		1
Students are part of the process		1
Students share instructor's excitement		1
Symbiosis		1
To narrow division between teacher and student		1
Cultural context impacts nature of engagement		2
▼ Instructor role (facilitator)		13
Have to be sensitive to students' facial expressions		3
Have to make eye contact with all students		1

Name	Color	Referen...
Have to make eye contact with all students		1
Instructor leads students to their guess		1
Instructors draw forth the learning		1
Instructors expected to engage students (hispanic)		1
Intuitive		2
Let students get involved in act of creation		1
Scans room		1
Try to get students to limit use of devices		1
When they get bored, instructor tells story		1
▼ Student role (active)		5
Participation and involvement and attention		1
Student effort		1
Students applying math outside of classroom		1
Students are involved		1
Students' active listening		1
▼ IDENTIFY ENGAGEMENT		52
'connected'		1
▼ Active		12
Active listening		1
Arms not folded		1
Movement		1
Nodding		4
Not unrelated chatting		2
Participating		1
They get animated		1
Writing in notebooks		1
▼ Asking and answering questions		8
Answering Qs		2
Ask interesting Qs		1
Asking Qs		4
Demonstrate effort to respond to Qs		1
▼ Display knowing		11
Can see in students eyes understanding or interest		1
Can see they are following along		2
Expression of understanding		2
Obvious who knows A vs who doesn't		1
You can see it in their faces		5
▼ Focused gaze (key directionality)		13
Following instructor		1
Looking at instructor		4
Looking at notes		1
Looking at the board		3
Making eye contact with instructor		2
Not looking at computers		1
Not on devices		1

Name	Color	Referen...
Looking alive		7
Awake		1
Excited		1
Ready to take notes		2
Showing attention		1
Showing interest		1
They look attentive		1
PARTICIPATION		44
Participation role		21
By encouraging participation the gap becomes less clear		1
Feedback and participation narrows the gap		1
Feedback lets instructor learn from students		1
Gauge		4
Enables you to gauge where class is		2
Participation to gauge learning		1
Trying to understand student line of thought		1
Instructor can adjust explanations according to feedback		1
Instructor gets students to create the lesson		1
Instructor using participation to lead them to the right ans...		1
Participation is a way to engage students		2
Participation is important		5
Participation is necessary feedback		1
Participation is part of process		1
Participation to feed forward their learning		1
Students participation feeds forward writing on the board		1
Participation strategies		23
Alternative feedback mechanisms		6
Gets students to participate by coming up to blackboard		1
Instructor prefers to go up and interact with students		1
Quizzes to see if they are following		1
Students can come to office hours to participate		1
Students can find alternative way to participate		1
Use feedback mechanisms to see if they are following		1
Asking		7
Calling on specific students to actively get more than s...		1
Check by asking if they are following		1
Gets students to participate by asking Qs		4
Throughout lecture asks students for feedback		1
Dialogic strategies		5
Asks students to 'give shout' if they are stuck		1
Encourages students to raise hand		1
Explains why she wants a response to encourage partici...		1
Promotes discussion over yes no responses		1
Rephrasing or breaking down questions into steps to ge...		1
Nonverbal strategies		3

Name	Color	Referen...
Nonverbal strategies		3
If students don't say anything, relies on nonverbal cues		1
Pausing to signal desire for response		1
Silence to direct student attention		1
Trickery		2
Answers self incorrectly to check student attention		1
Pretending to be puzzled so students participate		1
WRITTEN RESPONSE		54
Excellent teacher		43
Approach to teaching		9
Concern for practice		4
Adabtable		2
Embraces flipped classroom model		1
Uses technology in the classroom		1
Commitment to teaching quality		1
Well prepared		1
Conveys admiration for subject		3
Recognizes and treats math as 'living subject'		1
Shares excitement for learning		1
Shares value of subject matter		1
Exemplify mathematician		2
Demonstrates professional practice of doing math		1
Inspires by example		1
Delivery of subject matter		15
Captivating		4
Chooses illuminating examples		1
Engages students		1
Make concept attractive		1
Uses colour		1
Comprehensible		4
Communicates effectively		1
Explains at most elementary level		1
Presents material clearly		1
Presents material logically		1
Interactive		3
Ensure comprehension		1
Faces students while teaching		1
Promotes student involvement		1
Multipurpose math		4
Diverse approaches to subject matter		1
Helps make connections beyond blackboard		1
Real-world examples		1
Teaching real-world applications		1
Teacher Persona		19
Expertise		2

Name	Color	Referen...
Promotes student involvement		1
Multipurpose math		4
Diverse approaches to subject matter		1
Helps make connections beyond blackboard		1
Real-world examples		1
Teaching real-world applications		1
Teacher Persona		19
Expertise		2
Knowledgeable		1
Real-world experience		1
Impassioned		4
Engaging		1
Inspiring		1
Motivating		1
Passionate		1
Receptive		6
Accessible		1
Approachable		1
Being more human to students		1
Humility		1
Open to learning		1
Patient		1
Values students		7
Care for students well-being		1
Care for students' progress		1
Connection with students		1
Doesn't play favourites		1
Personal but professional		1
Respectful		1
Sympathetic to students		1
Needs improvement		11
Mismatch of expectations		4
All-knowing		1
Assuming too much of students		1
Emphasizing methods over concepts		1
Too much attention to procedural math not used in prac...		1
Student disconnect		3
Avoids eye contact		1
Doesn't listen to students		1
Leaving gaps		1
Teaching disconnect		4
Doesn't trust teaching skills		1
Lacks passion		1
Need better ways to explain concepts		1
Not enough examples prepared		1

Screenshot of multimodal coding (NVivo 11)

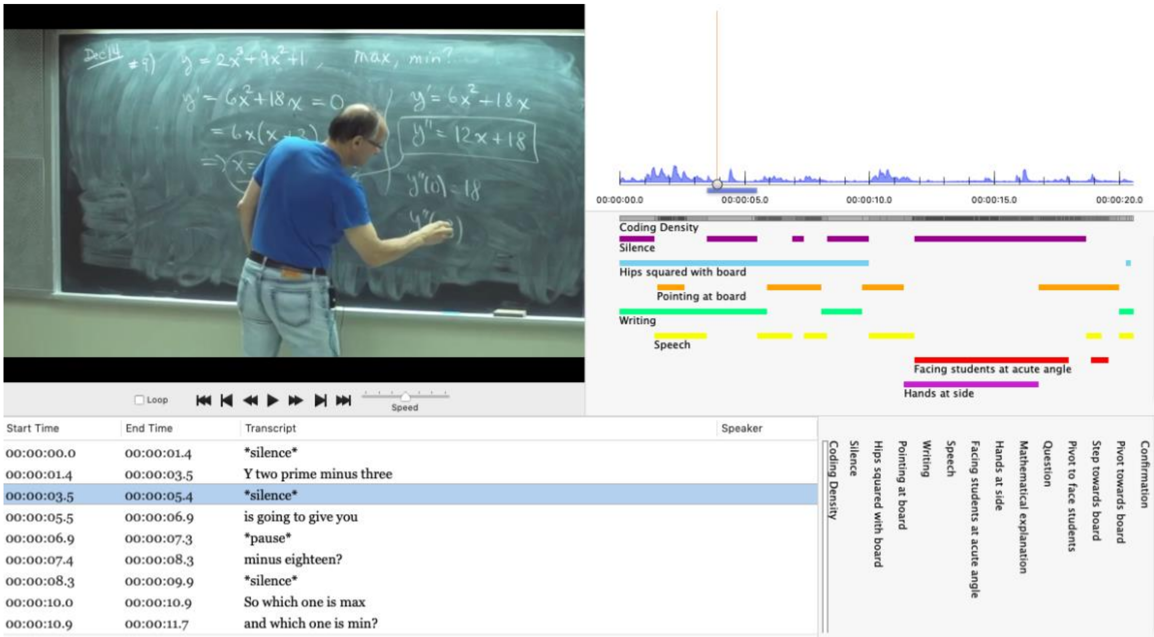


Figure 36. Screenshot of descriptive coding tree for multimodal coding (NVivo 11).

Name	Sources	References
Body orientation	1	7
Board	1	4
Hips squared with board	1	2
Pivot towards board	1	1
Step towards board	1	1
Students	1	3
Facing students at acute angle	1	2
Pivot to face students	1	1
Gaze	1	26
@Board	1	13
Line shift	1	3
Ongoing writing	1	5
Past writing	1	5
@past writing (left)	1	2
@past writing (newest line)	1	1
@past writing (up)	1	2
@Students	1	9
@specific student (right)	1	2
direct (left)	1	1
direct (right)	1	2
over shoulder (right)	1	1
pan	1	3
Shift	1	4
Board to students	1	2
Students to board	1	2
Gesture	1	8
Pointing at board	1	7
Close	1	3
Distant	1	1
Mid	1	2
Touching	1	1
Rest position	1	1
Hands at side	1	1
Silence	1	6
Speech	1	12
Confirmation	1	1
Mathematical explanation	1	2
Question	1	3
Self-directed	1	1
Student-directed (open)	1	1
Student-directed (specific)	1	1
Student response	1	2
Writing	1	3

Appendix G: Descriptive Statistics of SR Responses to Likert Items

Table 7. Reliability statistics of Likert items.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.846	.841	31

Table 8. Mode and range of responses to Likert items.

Statistics

	N		Mode	Range
	Valid	Missing		
Speaks clearly	44	0	1.00	2.00
Checks to make sure students grasp the material	42	2	1.00	3.00
Asks questions	44	0	2.00	2.00
Is encouraging	44	0	1.00	3.00
Is an expert in the field	43	1	1.00	3.00
Writes neatly and clearly on the board	44	0	1.00	3.00
Uses new technology in the classroom	44	0	3.00	4.00
Is excited about the material	44	0	2.00	3.00
Allows time to take notes	44	0	1.00	2.00
Relates to being a student	44	0	2.00	3.00
Encourages collaboration in the lecture classroom	44	0	3.00	3.00
Is friendly	44	0	1.00	4.00
Provides real world examples	44	0	2.00[a]	4.00
Uses physical objects to demonstrate abstract concepts	44	0	2.00	4.00
Faces the students when explaining material	44	0	2.00	3.00
Uses humour in the classroom	44	0	3.00	3.00
Becomes animated when explaining material	44	0	3.00	3.00
Looks around the room to "check in" with students	44	0	2.00[a]	2.00
Feels there is no question that is too elementary	44	0	1.00	4.00
Is approachable	44	0	1.00	2.00
Is able to explain content clearly	44	0	1.00	2.00
Moves around the room	44	0	3.00	4.00
Describes the beauty of math	44	0	3.00	4.00
Is focused mainly on the chalkboard	44	0	3.00[a]	4.00
Speaks quickly	44	0	4.00	3.00
Promotes class discussion	44	0	2.00[a]	4.00
Is serious and professional	44	0	3.00	4.00
Organizes group work and discussions	44	0	3.00	4.00
Does not stray from mathematical content	44	0	2.00[a]	4.00
Organizes the chalkboard notes in a way that is easy to follow	44	0	1.00	3.00
Avoids negative evaluation of students	44	0	1.00	4.00

a. Multiple modes exist. The smallest value is shown

Table 9. Mean and standard deviation of responses to Likert items.

	Mean	Std. Deviation	N
Speaks clearly	1.3333	.52576	42
Checks to make sure students grasp the material	1.6190	.76357	42
Asks questions	1.9286	.71202	42
Is encouraging	1.8333	.85302	42
Is an expert in the field	1.7143	.83478	42
Writes neatly and clearly on the board	1.4048	.70051	42
Uses new technology in the classroom	2.7381	1.03734	42
Is excited about the material	1.9524	.82499	42
Allows time to take notes	1.5714	.63025	42
Relates to being a student	2.0714	.86653	42
Encourages collaboration in the lecture classroom	2.3333	1.00406	42
Is friendly	2.0238	1.02382	42
Provides real world examples	2.4286	1.06251	42
Uses physical objects to demonstrate abstract concepts	2.3810	1.03482	42
Faces the students when explaining material	1.8571	.78310	42
Uses humour in the classroom	2.1190	.88902	42
Becomes animated when explaining material	2.2857	.91826	42
Looks around the room to "check in" with students	2.0952	.79048	42
Feels there is no question that is too elementary	1.8571	1.07230	42
Is approachable	1.3095	.51741	42
Is able to explain content clearly	1.3095	.56258	42
Moves around the room	2.7381	1.06059	42
Describes the beauty of math	2.8095	1.17366	42
Is focused mainly on the chalkboard	3.4524	.88902	42
Speaks quickly	3.9048	.93207	42
Promotes class discussion	2.9286	1.13466	42
Is serious and professional	2.6190	.96151	42
Organizes group work and discussions	2.8571	1.15972	42
Does not stray from mathematical content	2.8571	1.04931	42
Organizes the chalkboard notes in a way that is easy to follow	1.5238	.70670	42
Avoids negative evaluation of students	2.2143	1.22047	42

Appendix H: Thematic Analysis of Written Responses to Open-Ended Questions

(Instructor Interviews)

Teaching Philosophy

- Exemplifies the professional mathematician
  - Demonstrates the professional practice of doing mathematics
  - Inspires students by example
  - Makes transparent the thinking process of doing mathematics in real-time
- Conveys admiration for subject matter
  - Shares with students an excitement for learning new things
  - Possesses a keen sense of the value of the subject matter and its current and future real-world applications beyond the classroom
  - Recognizes that mathematics is a "living subject" and treats it as such
- Shows a regard for the practice of teaching
  - Maintains a commitment to teaching quality
  - Places an importance on preparedness
  - Remains adaptable and receptive to new teaching tools, technologies, and needs of students

Delivery of subject matter

- Delivery is comprehensible and compelling
  - Presents material clearly and logically
  - Communicates effectively
  - Possesses the ability to explain material at the most elementary level
  - Makes concept attractive (e.g., chooses illuminating examples, uses colour)
- Lectures are interactive
  - Promotes student involvement and participation
  - Faces students while teaching, looks around the classroom, makes eye contact with students
  - Checks in with students to ensure comprehension before moving on
- Subject matter is extended beyond the immediate context
  - Helps the students make connections between mathematics on the blackboard and other areas of mathematics or STEM discipline(s) and/or professional industries
  - Provides real-world examples

Teaching persona

- Instructor is passionate and knowledgeable
  - Demonstrates passion for teaching and learning
  - Possesses rich knowledgebase and real-world experience
  - Inspires students and provides motivation
  - Understands a variety of approaches to the subject matter
- Students are valued and respected
  - Establishes a rapport and maintains connection with students
  - Shows care for students' well-being and progress
  - Is sympathetic to the student experience

  - Respects students and shows no preferential treatment
  - Behaves is a way that is personal but professional
- Instructor is receptive and 'open'
  - Appears approachable, accessible, and human
  - Exercises humility and patience
  - Remains open to learning new things and learning from students

Areas for improvement

- Instructor's expectations are incongruent with students'
  - Assumes too much of students and/or leaves too many gaps in explanations
  - Teaches "over students heads", conveys omniscience
  - Overemphasizes methods or procedural math that may not be relatable to students outside the mathematics discipline
- Instructor appears to be disconnected from students and/or teaching
  - Avoids eye contact with students
  - Focuses on presenting material over listening to students
  - Lacks passion for material and/or confidence in teaching skills
  - Feels unprepared to explain content or present sufficient examples

Appendix I: Sample of Manual Multimodal Coding with Excel Spreadsheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Frame#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
2	Time stamp	00:00:00.00	00:00:01.41	00:00:01.54	00:00:02.66	00:00:03.46	00:00:05.49	00:00:05.88	00:00:07.00	00:00:07.34	00:00:08.09	00:00:09.71	00:00:10.67	00:00:11.76	00:00:15.30	00:00:16.81	00:00:17.30	00:00:17.68	00:00:18.22	00:00:18.72	00:00:19.14	00:00:20.02	00:00:20.520
3	Language	W	WT(B)	WT(B)	WT(B)	W	WT(B)	T(B)^	P	T(B)^?(SD)	W	T?(G)	T?(G)	S	S	S	SL	SL	S>T?(S1)	T?(S1)	SL	T©	WT(B)
4	Orientation	FB	FB	FB+	FB	FB	FB	FB	FB	FB	FB	FBt>S	FS	FS	FS	FS	FS	FS	FS	FS+	FSt>B	FB	FB
5	Gaze	GB>	GB>	<GB	GB>	GB>	GB^	GB^	GBvS	GSv	GB>	GtSv	GSv	GS<v>	GS1<	GS1<	GS1<	GtB>	GB>	GtS1<	GtB>	GB>	GB>
6	Gesture	W	W	CB	W	W	W	DTB	DTB(H)	DTB	W	DCB	DMB	RP	RP	DDB	DDB>	DMB	DCB	DCB	Dr	Wprep	W
7	Proximity	B=	B=	B=	B=	B=	B=	B=	B=	B=	B=	RLstep	Llpivot	➢ Won RL	➢ Won RL	➢ Won RL	➢ Won RL	Wshift LL	Step>B	F=	Turn	Rlstep	B=

Key

Symbol	Meaning	Note
Language	Writing, Talking, Both(Commentary), Asking question, Gesturing, Silence, Pauses, Listening	
W	Writing	
WT(B)	Writing+Talking (commentary)	
T(B)^	Commenary with raised intonation	
P	Pause	
T(B)^?(SD)	Commenary with raised intonation to form question directed at the students	
T?G	Asking a question and gesturing	
S	Total silence	
SL	Silently listening	
S>T?(S1)	Silence transitioning to asking a question to a specific student	
T?(S1)	Asking a question to a specific student	
T©	Confirming	
Orientation	Facing board, students, partial shifts	
FB	Facing board	
FB+	Facing board and multiple points of contact with board	
FBt>S	Facing board turning to face students	
FS	Facing students	
FS+	Facing student(s) and narrowing proximity	
Gaze	Gaze directio <^v> signal orientation of gaze (NorthSouthEastWest (Board = North)	
GB>	Gaze directed at board (in front)	
<GB	Gaze directed at board (left or previous writing)	
GB^	Gaze directed at board (up)	
GBvS	Gaze directed at board (over shoulder slightly towards students)	
GSv	Gaze directed at students (in front)	
GtSv	Gaze shift to students	
GS<v>	Pan-gaze	
GS1<	Gaze directed at individual student (left)	
GtB>	Gaze transition to board	
GtS1<	Gaze transition to individual student	

Key

Symbol	Meaning	Note
Gesture	Describes ges	If no gesture is named = occluded gesture
W	Writing	
CB	Gesture to chalk board (close)	
DTB(H)	Deictic touching board (Hold)	
DTB	Deictic touching board	
DCB	Deictic close to board	
DMB	Deictic midground to board	
DDB	Deictic distant ground to board	
RP	Rest position	
DDB>	Deictic distant ground to board moving toward board	
Dr	Drop hand	
Wprep	Preparing to write	
Proximity	Implies orien = implies squares hips ➢ implies 3/4turn	
B=	Hips squared to board	
RLstep	Right leg step out	
Llpivot	Left leg pivot	
➢ Won RL	Weight on right leg	
Wshift LL	Weight shift to left leg	
Step>B	Step towards board	
F=	Hips squared to students	
Turn	Turn towards board	
Rlstep	Right leg step towards board	