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STUDENT-DRIVEN INQUIRY-BASED SCIENCE EDUCATION IN LUXEMBOURG PRIMARY SCHOOL CONTEXTS

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Abstract

STUDENT-DRIVEN INQUIRY-BASED SCIENCE EDUCATION
IN LUXEMBOURG PRIMARY SCHOOL CONTEXTS

By
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This study examined the use of a student-driven inquiry-based science education instructional approach designed specifically to meet the contextualized needs of Luxembourg primary schools. The key issues, namely an increasing linguistically diverse student population and limited instructional time for science, were considered in the design of the instructional approach. Drawing on theories of dialogic inquiry, the instructional approach engages students in asking questions and designing investigations to build their science understanding. This interpretive qualitative study utilized a multi-perspective approach to analyse how teachers used the instructional approach in their classrooms and explored two overarching research questions:

i. What instructional opportunities does Science Workshop, an inquiry-based student-driven science instructional approach, afford when used in Luxembourg primary classrooms?
ii. What does analysis of interactions in these contexts reveal about inquiry-based science instruction in multilingual classrooms?

Qualitative methodologies, specifically case studies of classroom implementation, were used to examine the use of the program teachers' adaptations of the program in their classrooms. I drew upon Bakhtinian notions of heteroglossia and dialogic pedagogies to examine the instructional opportunities afforded. Interaction analysis was used to examine instruction in a focal classroom when the inquiry-based approach was used. Analyses rooted in sociocultural theoretical frameworks of science and language learning revealed three key contributions toward the use of IBSE in Luxembourg primary schools. First, the key characteristics of teacher professional learning opportunities that supported teachers' use of the program in Luxembourg, which included workshops, material support, and opportunities to share implementation cases. Second, the ways in which ritualized instructional components afford students spaces to engage on micro-scales in building synchronous interactions during science investigations were revealed. Third, that the science notebooks can position students to engage in dialogic discussions surrounding science investigations. Taken together, these interrelated points contribute to an understanding of the use of student-driven instructional approaches in multilingual science classrooms in general, while revealing implications for the use of inquiry-based science instructional approaches in Luxembourg primary schools specifically.

Keywords: inquiry-based science instruction, multilingual, plurilingual, multimodal, interpretive, interaction analysis, voice as resource, heteroglossia, dialogic

Dedication

To those who ask, *what do you think?*
then take the time to listen.

To my partner, my children, my family…
you have taught me how to listen,
and helped me find my voice.
Thank you.

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FP7	7th Framework Programme
IBSE	inquiry-based science education
IR	interaction ritual
IRT	Interaction Ritual Theory
MENFP	Ministère de l'Éducation nationale et de la Formation professionnelle (Luxembourg Ministry of Education)
MENJE	Ministère de l'Éducation nationale, de l'Enfance et de la Jeunesse (Luxembourg Ministry of Education)
NRC	National Research Council (The United States of America)
OECD	Organization for Economic Coopration and Development
SSS	semiotic social space
STATEC	Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg
TPD	teacher professional development

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CHAPTER 1

SITUATING THE NEED FOR STUDENT-DRIVEN INQUIRY-BASED SCIENCE INSTRUCTION IN LUXEMBOURG PRIMARY SCHOOLS

In January of 2015, our research team had just finished co-teaching an inquiry-based science unit at a public school in Luxembourg City. My research colleagues, Christina Siry and Jana Haus, and I conducted student focus-group interviews to ask the ten-year-old students their perspectives on working in inquiry-based ways during science instruction. We structured these conversations around questions such as *Did you like asking questions about science phenomena and conducting investigations? How did you decide which questions to investigate?*. During one of these focus groups, the conversation unfolded to discuss students' experiences trying out their own ideas and making choices regarding schoolwork, and the following interaction occurred:

Chris:	Do you often have the opportunity to think about things and try them in school?
Student 1:	Yes.
Jana:	Yes? when then?
Student 1:	No…but no.
Student 2:	In school? To either do the homework correct or not.
	(Everyone laughs)

This scene ends with laughter, yet Student 2's response accurately reflects the nature of science instruction in many primary schools in Luxembourg. As Student 2 states, students have limited choices in their everyday schooling experiences, and as he astutely points out, have a choice only in deciding to do their homework correctly, or not. Science instruction in Luxembourg primary schools is typically taught using transmission models of instruction that position students to learn science facts (Faber & Freilinger, 2005). This lack of student choice in Luxembourg primary schools in general, and during science instruction in particular, sits in stark contrast to the student-driven inquiry-based science education (IBSE) instructional methods recommended by leading science education groups in Western European and American contexts (see for example Eurydice, 2006; National Research Council (NRC), 2012; Rocard et al., 2007). Meaningful and effective inquiry-based instruction at the primary level can engage students in asking questions, designing investigations, and working as communities of scientists to build science understandings (e.g. Minner, Levy, & Century, 2010). The research I present in this dissertation analyses a student-driven IBSE instructional program that positions students to pose questions about science phenomena and design and conduct investigations based on their questions. I designed Science Workshop[1] to specifically address the current needs of Luxembourg primary schools, which I call Science Workshop. The contextual needs, as well as the decisions that went into the development of the instructional approach are detailed in the sections that follow.

The study I present in this dissertation examines student voice as a driver of inquiry-based instructional opportunities in Luxembourg primary classrooms. While focus of the research is specifically on science instruction, the overarching focus that cuts across multiple aspects of the dissertation is the notion of voice. Voice in both

[1]Science Workshop is the name of the teacher professional development (TPD) and instructional approach I designed and implemented during the course of this dissertation. The format of the TPD and instruction are specific to the Luxembourg context, and build from prior similar inquiry-based science workshop instructional approaches, such as Saul, Reardon, Pearce, Dieckman, & Neutze (2003).

literal, and metaphorical forms. By this I mean the voices students contribute in the process of engaging in science learning and examining how student voice in diverse forms can engage in science learning. In this sense, in this study voice is a process, a position, and a consideration of voice links the multiple analyses contained in this study.

Throughout the analyses I present in the chapters to come, I draw from and build upon Bakhtin's (1981; 1986) notions of *multivoicedness* and *heteroglossia*. First, I use heteroglossia as a lens to situate the different, at times contentious, voices presently guiding the form of primary science instruction in Luxembourg primary schools. Second, I draw upon heteroglossia as a lens to view resources and differences that the analyses I present in this dissertation bring to light when Science Workshop is used in Luxembourg primary classroom contexts. In conclusion, I describe the multiple voices that emerged in analysis and elaborate on what is learned from tuning into these voices in both instructional, as well as research study decisions. Thus, notions of voice are central both to the instructional approach that is the focus of this study, and as a theoretical lens through which to view the analyses.

What is Science Workshop?

The instructional approach that is the focal point of this study is termed Science Workshop. I designed Science Workshop as an IBSE pedagogical approach that can be adapted for use with multiple age-groups to support students in questioning, investigating, building understanding through discussion and representation with peers, and communicating their results through the use of multiple semiotic resources. Science Workshop was designed to support both language literacy and science learning. It is grounded in three key theoretical features arising from practices science education research has shown can be effective; namely, student-driven instructional approaches. Specifically, i. the use of students' questions to drive IBSE (Exploratorium, 2006; Gallas, 1995; NGSS Lead States, 2013), ii. the integration of language literacy and inquiry-based science instruction (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012; Lee & Fradd, 1998; Stoddart, Solis, Tolbert, & Bravo, 2010; Varelas & Pappas, 2013), and iii. the use of dialogic pedagogies that create spaces for diverse student voices (Haneda & Wells, 2010; Mercer, Dawes, & Staarman, 2009). These three theoretical underpinnings and three key features of the instructional approach are further elaborated on in Chapter 2.

Inquiry-based science education. Education research has established the merits of inquiry-based science education (IBSE) and its positive influence on student science learning (e.g. Minner et al., 2010). The notion of inquiry-based instruction is not new. Dewey, a former American science teacher and philosopher proposed inquiry methods (1910) for science teaching as an approach to engage students in problem solving and thinking critically in the service of learning science (as described in Barrow, 2006). In the late 1950s, early 1960s, with the dawning of the Space Race, a renewed interest in inquiry science instruction developed when the American National Science Foundation (NSF) supported the development of a physics curriculum (Physics Science Curriculum Study, 1956, described in DeBoer, 1991). This, and additional NSF-funded science curricula developed at the time, engaged students in thinking a scientists (DeBoer, 1981) and engaged students in science processes (Barrow, 2006). A wide body of research now documents the ways IBSE positions students to thinking critically, and is beneficial for learning in ways that go beyond learning just science facts (see Minner et al., 2010 for a summary). In particular, IBSE has resulted in positive effects on pupils' learning and understanding of science at the primary school (Rocard et al., 2007). In contrast to more textbookdriven forms of science education that are dominated by teacher-direct lectures, IBSE values students' questions, and engages students in constructing science knowledge in deep and meaningful contexts (Worth, Saltiel, & Duque, 2010; National Research Council [NRC], 1996). IBSE is rooted in constructivist theories of learning and engages students in actively making observations, posing questions, planning investigations, reviewing experimental evidence, interpreting data, proposing explanations, and communicating results to diverse audiences (NRC, 2012; Minner et al., 2010; Worth et al., 2010). Through inquiry-oriented instruction, students are able to practice science in ways that promote dialogue and critical thinking.

IBSE can position students to participate in a community of practice (Lave & Wegner, 1991) in ways that mirror how scientists communicate and work, and thus engage in authentic science inquiry (Crawford, 2012). In their study of students' participation in authentic inquiry, Rivera Maulucci, Brown, Grey and Sullivan (2014) worked over a three-week period with students engaged in science inquiry investigations designed by the students themselves. Analysis of teachers' journal entries, student work, and semi-structured interviews revealed that authentic inquiry-based science opportunities afforded the students with a sense of agency and positioned them to work in ways that allowed them to draw from their personal perspectives, but in collaboration with their colleagues, and as such to act collectively to inquire, and thus learn science.

Inquiry-based science education with plurilingual[2] students. There exists a wide body of research that documents the benefits of inquiry-based science

[2] The term *plurilingual* is used, as recommended by the Council of Europe to describe students who possess diverse language repertoires consisting of various combinations of national languages and communicative resources, while *multilingual* is used to describe *spaces* of varied language use. The research I present here builds on prior science education research that uses, for example, terms such as *multilingual students*, *language-learners*, and *English language learners* (ELLs), to refer to students

instruction for language learners (e.g. Lee, Quinn, & Valdés, 2013; Quinn, Lee & Valdés, 2012; Stoddart, Pinal, Latzke, & Canaday, 2002). For students learning science through a second or third language, as was the case of the plurilingual participants in this study, student-driven inquiry-based science instruction provides opportunities to engage in both the practices of science, and also in meaningful contextualised science conversations with peers (Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). Research studies have shown that the use of IBSE in primary classrooms provides students with opportunities to think more critically and interact with concrete phenomena in ways that build their understanding of science phenomena, and their ability to work in communities of scientists. Students are positioned to dialogically interact with peers as they engage in science (Lee, Deaktor, Hart, Cuevas, & Enders, 2005). Haneda and Wells (2010) demonstrated that dialogic inquiry-based science instruction supported multilingual students in not only learning science content, but also in the engagement of science process skills and in the development of science discourse.

There are many flagship projects that demonstrate how this type of student-centred context-rich inquiry instruction can be successfully used in primary school classrooms (see for example Espinet et al., 2017; Varelas & Pappas, 2013). These projects show how, when positioned to engage in the processes of science, plurilingual students benefit from student-centred instructional approaches (Llosa et al., 2016). Thus, IBSE has been established as a pedagogy that provides students with experiential contexts from which they can strengthen both their language abilities and

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who are learning through a language they may not yet have mastered, or who are learning in a language that is different from their home language(s). See European Council (2001), science understandings (Fradd & Lee, 1999; Pearson, Moje, & Greenleaf, 2010; Roseberry, Warren, & Conant, 1992; Stoddart, et al., 2002).

Student-driven science instruction. While inquiry-based science instruction often implies that students direct the course of investigations, research has documented that inquiry-based science instruction can be implemented in prescriptive ways as well (Anderson, 2002; Fogleman, McNeill, & Krajcik, 2011). These more closed or teacher-directed forms of inquiry can still position students to engage in science practices, but in ways that limit students' opportunities to voice their interests and to direct investigations. For this reason, it is important to consider not only the instructional approach, but also how students are positioned in this process. In student-driven approaches, students are afforded opportunities to contribute their voice, and draw upon their resources to direct science learning (Haneda & Wells, 2010). Participatory approaches, such as IBSE instruction, involve students in ways that create meaningful learning contexts based on their questions and experiences with scientific phenomena (Maskiewicz & Winters, 2012; Siry & Kremer, 2011).

Thus, I designed Science Workshop, to purposefully incorporate *student-driven* inquiry. This means that students are supported in asking questions, and subsequently in using these questions to design science investigations. In this way, science instruction arises from students voices and positions students to draw on their diverse perspectives as resources (Gallas, 1995; Gonsalves, Seiler, & Salter, 2010). While a large body of research has established the benefits of IBSE, there is a dearth of research that explores the use of such pedagogical approaches in Luxembourg primary schools. This dissertation presents a qualitative interpretive study that explores one such inquiry-based instructional approach, and in doing so, contributes to the research focused on the use of IBSE instruction in multilingual contexts.

Why Science Workshop?

Here, I explain the current state of science education in Luxembourg primary school contexts as a driver for the development of Science Workshop. To assist this explanation, I draw upon Bakhtin's (1981) notion of *heteroglossia*. Heteroglossia as a lens used to elaborate on this context allows me to describe some of the transnational, national and local voices that influence the forms of science instruction used in Luxembourg primary schools at the time this research was conducted. I then elaborate on the differences and / or tensions that exist among these voices, and how they contribute to the instructional contexts in which this research was conducted.

Luxembourg's trilingual public school system. Luxembourg is a small European country nestled between two francophone countries (France and the Wallonia region of Belgium) and one Germanic country (Germany). Luxembourg is a triglossic (Horner & Weber, 2008) country that has three languages used in everyday life, the national language of Luxembourgish, and the official languages of German and French. Luxembourg's triglossic language landscape is further complexified because, unlike many of its neighbouring European countries where differing language communities reside next to each other (e.g. Switzerland), language diversity in Luxembourg is superposed (Horner & Weber, 2008). This means that linguistic resource use overlaps, resulting in the use of multiple language resources within each context (Fehlen, Legrand, Piroth & Schmit, 1998; Maurer-Hetto, 2009). To add to this language complexity, 47% of Luxembourg residents are not Luxembourg nationals (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg (STATEC), 2016). Thus, a majority of children growing up in Luxembourg do not speak Luxembourgish at home with their parents and family members.

Aligned with the language context of the country, Luxembourg's public primary schools (Education fondamentale[3]) are trilingual. By the end of primary school, at age twelve, students are expected to demonstrate competence in the three languages. Beginning from age three (an optional year of schooling) and age four (the start of compulsory schooling), students and teachers interact in Luxembourgish. From the third compulsory year of primary school onwards, at six years of age, the national curriculum (plan d'études) specifies literacy learning goals in German, subject area instruction (science, math, geography, and history) in German, as well as French literacy beginning from age seven.

Luxembourgish literacy is allocated relatively little instructional time in the primary school curriculum, on average one hour per week. Students are immersed in speaking and working in Luxembourgish the first two years of schooling, but then Luxembourgish is relegated to mainly communicative purposes, and is not typically treated through formal literacy instruction, further complicating students' triglossic school learning trajectories (Weth, 2015).

While the Luxembourg primary curriculum is trilingual, the approach of both language and science instruction establishes a *monocultural habitus* (Maurer-Hetto & Roth-Dury, 2005). García (2009) explains that monoglossic instructional approaches position students in ways that separate their linguistic engagement by requiring the use of one language at a time. In Luxembourg's primary classrooms, this means students typically are positioned to use only German during German instruction and only French during French instruction, thus separating the use of languages into discrete compartments (García & Kleyn, 2016). In these monoglossic spaces, students are deprived of opportunities to draw from and build across their diverse linguistic

[3] The terms used by the Luxembourg public school system are provided in parentheses.

repertoires composed of diverse communicative resources (García & Kleyn, 2016). Monoglossic instructional approaches, such as those used in Luxembourg at the time of this study, undercut opportunities to support language development in the context of science instruction in ways that honour the diverse communicative resources of all students, and particularly for plurilingual students.

For primary students, whose first language is a language other than Luxembourgish, the challenge to succeed in the trilingual school system can be insurmountable. Student failure rates for non-Luxembourg students are much higher than those for students who speak Luxembourgish at home (STATEC, 2016). Changes to instructional approaches in ways that build upon the diversity of students' linguistic repertoires as a resource, and that are rooted in research-based instructional approaches, are seldom discussed in ways that create systemic changes in schooling. This reflects a greater national struggle between voices (i.e. political parties) that advocate to *remain as Luxembourg is* but at the same time recognize the need for the Luxembourg school system to adapt to growing societal diversity. Elmesky (2011) explains, "Even during an era of cultural globalization where diversity, hybridity, and heterogeneity prevail, educational institutions remain unchanged and racially and economically marginalized students continue to experience a sense of exclusion in school" (p. 49). This underscores the need for instructional approaches that create spaces for students to employ heterogeneous linguistic and cultural resources when learning in general, and particularly when learning science.

Primary science instruction in Luxembourg. In 2011, the Luxembourg Ministry of Education (Ministère de l'Éducation nationale et de la Formation professionnelle, MENFP) released a new national curriculum (plan d'études) that set out competency-based curricular guidelines for all primary level science instruction

(MENFP, 2011). This curriculum differed from prior Luxembourg national curricular plans in that it included ways of engaging students in the practices of science that are aligned with ‘best practices’ in inquiry-based science education (NGSS Lead States, 2013; NRC, 2012). In this regard, the plan d’études details guidelines for instruction that include both science content and process learning goals. The new competencies can be seen as an attempt by the Luxembourg Ministry of Education to shift how teachers teach and evaluate science learning from the former transmission-based methods of teaching, that required students to learn science facts, to more competency-based methods that engage students in the processes of science.

Although the national curriculum has been revised to incorporate active pedagogical approaches for science instruction, science is assigned relatively little time in the weekly curricular plan. Students aged 6 through 12 attend primary school for a total of 28 hours a week. During these 28 hours, students aged 6 through 8 engage in 3 hours of science instruction. This constitutes 10.7% of their instructional time in school, with languages by contrast, comprising 35.7% of the curriculum (MENFP, 2011; as explained in Andersen, Siry & Hengesch, 2015).

The number of science lessons per week for 8 through 10-year-old students is reduced to 2 lessons a week, or 7.1% of instructional time, in order to provide additional time for German and French language instruction. For students aged 10 through 12, the number of hours dedicated to natural science instruction (*sciences naturelles)* is further reduced to 1 lesson per week, or 3.6% of instructional time. Relative to neighbouring countries, there is very little time set aside for science instruction (Andersen, Siry, & Hengesch, 2015). It positions teachers to engage students in science processes in relative short instructional time frames. Research on the use of inquiry-based and student-driven forms of science instruction has documented the need for adequate classroom time dedicated to student exploration, investigation, and communication (e.g. Anderson, 2002). Thus, given the competency-based national curriculum, and the relatively few hours specified for science, Luxembourg teachers are challenged to implement inquiry-based forms of science in few instructional hours.

Results from past international measures of students' science competencies, specifically the Programme for International Student Assessment (PISA) test administered by the Organization for Economic Cooperation and Development, demonstrated that Luxembourg's students scored 3 percentage points below the OECD average in 2015 on measure of science competency, and has consistently scored below the OECD average since 2006 (Boehm, Ugen, Fischbach, Keller, & Lorphelin, 2017). While the validity of the OECD exam as an appropriate measure of student ability remains in question, in particular in countries with complex linguistic landscapes such as Luxembourg (Sjøberg, 2015), these results provide a glimpse into the challenges facing science instruction in Luxembourg. Additionally, the PISA 2015 results indicated that socioeconomic status, migration history, as well as languages spoken at home, play a significant role in the performance of Luxembourgish students on the test (OECD, 2016). These results underscore the need to implement instructional approaches that support all students, regardless of socioeconomic or linguistic profile, in obtaining equitable education in the sciences.

Past inquiry-based science education projects in Luxembourg. Over the past ten years, there have been a handful of projects of varying sizes that have worked to address science teaching and learning in Luxembourg. One such project was the European Union-wide POLLEN Project (POLLEN: Seed cities for science: A community approach for a sustainable growth of science education in Europe) implemented from 2006 through 2009. This was funded under the European Union's 7th Framework Programme (FP7) Fibonacci Project (www.fibonacci-project.eu). When I relocated to Luxembourg in 2010, I met Christina Siry, who was at the time the coordinator of the Fibonacci Project in Luxembourg.

The main objective of the Fibonacci Project was to support the dissemination of inquiry-based mathematics and science instruction throughout the European Union, in ways that fit with the local needs of each participating centre, of which Luxembourg was one. The FP7-funded project was coordinated by La main à la pâte (Académie des sciences, Institut National de Recherche Pédagogique, École normale supérieure, Paris, France), and Bayreuth University, Germany. The specific goals for the Luxembourg Fibonacci Project included the promotion of IBSE instructional approaches in primary schools in support of the Luxembourg's competency-based curriculum, by conceiving and organizing a professional development program for teachers to support IBSE instruction through in-service training (2010-2011 and 2011-2012), as well as to promote, through IBSE instructional approaches, students' use of German, the language of instruction. During our work in primary schools, and with teachers in workshops and their classrooms, I was afforded first-hand and second-hand views of teachers' needs as described by the teachers during teacher professional development workshops and interviews, and as elaborated on through their feedback and requests throughout the professional development process. It was during this work that teachers who were willing to implement IBSE voiced two main concerns; first, a lack of instructional time to implement IBSE due to a language-dominated national curriculum, and second, the need for curricular models adapted specifically to the Luxembourg language context.

Summarizing the tensions

Taken together, there are calls for policy from internationally positioned institutions, national curricular documents, and teachers who support the use of inquiry-based instruction in Luxembourg. So, the question remains, *why is IBSE not used?* The answer resides in a number of tensions that still provide barriers at multiple levels, which are true in many educational systems, not just in Luxembourg (Anderson, 2002; Minner et al., 2010). Table 1.1, summarizes these calls at two levels, the international and the national, and lists the associated tensions that I have briefly discussed in prior sections specific to Luxembourg. While this list is by no means exhaustive, I present it here to summarize the wider policy and socio-historical context in which I conducted this study.

	Policy documents supporting the use of IBSE	**Tensions related to IBSE use**
Calls from International contexts	• Inquiry-based science instructional practices (Rocard et al., 2007) • Literacy integrated practices (Eurydice, 2006; Osborne & Dillon, 2008)	• Globally available IBSE programs, but removed from the Luxembourg curricular context, globally relevant but not locally adaptable in sustainable ways (Fibonacci, Luxembourg)
Call from Luxembourg context	• Competency-based science curricular plan (MENFP, 2011)	• Lack of curricular materials • Lack of time • Persisting use of transmission-based forms of science instruction and science curricular topics established in 1989 • Monoglossic approaches to language and science instruction

Table 1.1. Summary of tensions related to the use of IBSE in Luxembourg

Based on what I came to know about science education in Luxembourg primary schools, I designed Science Workshop as a way to flexibly work within the current instructional program while striving to open up instructional approaches that are monoglossic and transmission-based. The approach that I studied in this dissertation aimed to shift science instruction to inquiry-based student-driven forms that create spaces for student voice, and that valorize students' resources (Gonsalves et al., 2010), yet that does so in ways that are adapted to the local contextualized needs of Luxembourg primary schools.

Heteroglossia as a lens

In this dissertation, I draw upon Bakhtin's concept of *heteroglossia* (1981) to position several different aspects of the research project I describe herein. First, I introduced heteroglossia in the prior sections as a lens to describe and position the different voices currently informing science education in Luxembourg, and to discuss the differences among them. Building on the description of this context, I next present the science program that I designed and supported teachers in using in Luxembourg public primary classrooms from 2014 through 2015. In the chapters to come, I use heteroglossia as a lens to examine not only the instructional spaces created, but also the interactions that occurred and the uses of voice and space that resulted. Before doing so, I present a review of the literature regarding heteroglossia and its use as a theoretical tool in education research.

Introducing the concept of heteroglossia. Bakhtin first introduced the concept of heteroglossia in his work presented in *The Dialogical Imagination* (1981) to push against monolingual discourse in the Soviet Union in the 1920s. Heteroglossia, in his theorization of the concept, implies that each act of speech (utterance) contains multiple voices, and that tensions often exist among these voices. While there is not one exact definition for the concept that was translated from his original writings in Russian, Pietikäinen and Dufa (2006) explain that Bakhtin's elaboration of the concept in Russian can best be described as a condition of intralingual diversity present in one's utterances within one national language. In a second elaboration of the concept, Busch (2014) details three forms of heteroglossia in Bakhtin's multi-layered conceptualization; multiple codes and languages, multidiscursivity, and multivoicedness. While scholars have interpreted heteroglossia in different ways, all converge on an understanding of the spoken in ways that view utterances as multi-layered and populated with differing, often conflicting, ideological viewpoints. In this way, examining heteroglossia is a way to draw attention to the multiple voices present in a speech utterance, and furthermore, as a way to draw a critical eye to the social complexities inherent in speech and voice. The concept of heteroglossia has since been utilized by social scientists from a range of disciplines, and in a variety of ways, to theorize the presence of multiple languages, voices, and use of semiotic resources (see for example Blackledge & Creese, 2014).

Heteroglossia as a research lens. Scholars have employed heteroglossia as a theoretical lens in education research in various ways. Past work includes studies that adopt a discourse analysis approach and identify varied voices present in a speech act, the various different semiotic resources used by those in interaction, or the multiple forms of voices present in a space, and to then expand on this by examining the tensions and differences present among the voices (Bailey, 2007). Blackledge and Creese (2014) in their edited volume *Heteroglossia as Practice and Pedagogy*, elaborate upon the usefulness of Bakhtin's concept of heteroglossia as a lens to examine "the social, political and historical implications of language use in practice" (p. 1). In their edited volume, they bring together a body of several research studies that draw upon heteroglossia as a lens to examine varied language use across a variety of contexts, including educational spaces. In the research they present, various analytical approaches are employed, but collectively the set of analyses asks how language is "shot through with multiple voices which constitute and are constitutive of social, political, and historical positions" (Blackledge & Creese, 2014, p. 13). They explain "heteroglossia provides a theoretical lens which enables us to understand *voice* as filled with social diversity" (p. 13). As their work demonstrates, heteroglossia can serve as a powerful theoretical lens by which to examine language and interaction at the level of utterances and people, and link it to the wider social, political and historical contexts in which they are occurring.

Heteroglossia as a lens in science education research. In the realm of science education research, scholars have increasingly used the notion of heteroglossia to examine voices and positioning and interactions in science classrooms. Kiramba (2016) conducted an ethnographic study of the heteroglossic communication practices of 9-12-year-old students and a science teacher in a Kenyan classroom. While national policy dictated students be taught using monolingual literacy approaches, her study elaborates on the translanguaging practices the teacher employs to assist students in using their plurilingual communicative resources while learning within the monolingual national language policy. She shows how the teacher legitimizes translanguaging as a way to assist students in accessing their out-of-school experiences and understandings as they participated in a science lesson. The use of heteroglossic practices, such as incorporating the use of more than one language in interaction, assisted the students in voicing their experiences in ways that increased their science meaning-making. The study also demonstrates how the students and teacher navigate the tensions between the plurilingual communicative repertoires and the monolingual national language policy, in ways that make space for diverse communicative practices during science instruction.

In a different application of heteroglossia as a theoretical lens, Kamberelis (2001) presented discourse analysis of classroom events to demonstrate how students employ hybrid discourse practices that construct (micro)cultures or "free spaces" (p.

85) utilizing combinations of their own voices within the larger authoritative context of the classroom. One event analysed is two 11-12-year-old students dissecting a barn owl pellet during science instruction. As they worked to dissect the pellet, they employed various voices (discourses), such as imitating voices from doctors and scientists from popular television and film genres, and at times incorporated mad scientist impressions. Overall, the two students switched and changed the framing of their discourses multiple times during the dissection. Through these changes in framing, the two students drew on many voices with different socio-cultural connections. Through their interactions in these voices, they constructed a hybrid space that assisted their science engagement and learning and that served to "contextualize the meanings of the materials" (p. 121) of the dissection and that helped the students make connections between the "disparate worlds of school life and everyday life" (p. 121). As the students performed the dissection, the small-group format of the science task provided space where heteroglossia was manifested in the students' interactions. They were able to draw from multiple discourses or voices from different aspects of their lives, as they participated in doing science.

In this study, I build on these prior studies and their conceptualizations of heteroglossia, but in novel ways and in the context of IBSE instruction in Luxembourg. As Blackledge and Creese (2014) explain: "heteroglossia provides a theoretical lens which enables us to understand *voice* as filled with social diversity" (p. 13). In this way, I will use heteroglossia as a lens to study diverse voices in IBSE in Luxembourg.

In this dissertation, I additionally draw upon Bakhtin's (1981; 1984) conceptualization of words as dialogic. In this sense "the word is not a material thing but rather the eternally mobile, eternally fickle medium of dialogic interaction"

(1984, p. 197), and as such involves two-sided acts of speech. Dialogic is a way of viewing the world and interactions. Languages, utterances, and people in a dialogic conceptualization of the world are involved in interactions that position them to listen to and respond to the other. In this sense, the listener and hearer always exists in relation to one another. Considered together, Bakhtin's concepts of *heteroglossia* and *dialogic* as grounding perspectives provide lens that enables one to conceptualize voice as multiple, dynamic and always existing in relation to another in specific cultural and historical contexts.

In summary, it is these concepts that I will put to further use in this dissertation, namely heteroglossia and dialogic pedagogy, as lenses to frame the analysis of the science instructional approach I designed, and to subsequently analyse the use of the IBSE program in multilingual classroom contexts in Luxembourg.

Theoretical Grounding

The present study is grounded in sociocultural views of learning and language use (Rogoff, 2003; Wertsch, 1993, 1994). It employs a multi-layered qualitative approach to examine the use of an inquiry-based science instructional approach in Luxembourg primary classrooms. The overarching goals of this study were to examine how teachers implemented the instructional approach in their classrooms, and once used, to analyse the interactions that emerged when students conducted inquiry investigations. As the nature of this study is emergent, (Morgan, 2008), responsive (Tobin, Elmesky, & Seiler, 2005) and interpretive (Erickson, 1986) there are subsets of questions that emerged through analysis. These questions are presented and elaborated on in the next three chapters (Chapters 2, 3, and 4) that follow. The research questions that guided the overarching study were:

i. What instructional opportunities does Science Workshop, an inquiry-based student-driven science instructional approach, afford when used in Luxembourg primary classrooms?

ii. What does analysis of interactions in these contexts reveal about inquiry-based science instruction in multilingual classrooms?

The research presented herein is innovative in that two ways. First, it explores the use of an instructional program tailored to the needs of primary science instruction in Luxembourg. Second, it examines how a student-driven IBSE instruction can successfully support students in participatory science practices in multilingual classroom contexts. As a result, the research I present herein draws on well-established theoretical perspectives, and applies them in novel ways to analyse the use of IBSE instruction in multilingual primary school contexts. I do this is in order to contribute to an understanding of science instruction in Luxembourg primary schools.

Sociocultural lenses

The sociocultural theories of science classrooms and learning in which this study is grounded elaborate on that culture is enacted in social spaces, where by human actors have access to symbolic, social and material resources, and these are in flux as actors take agency (Sewell, 1992; 1999). Interactions in classrooms are mediated by social, material, temporal, historical and cultural contextual settings (Wertsch, 1994). Through the frameworks that I draw upon, events and actions cannot be separated from the settings in which they occur. Thereby, "meaning making is a material process, transactive between persons and things, and does not belong to an autonomous Cartesian parallel universe of purely mental realities" (Lemke, 2001, p. 309). Learning, in this view, arises from the interaction of all aspects of human activity, and is embodied and created in and through culturally contextualized transactions (Lemke, 1990). Cognition is “distributed between persons and artefacts, and persons and persons, mediated by artefacts, discourses, (and) symbolic representations” (Lemke, 1990, p. 298). Therein, language is a resource that is made socially available for making meaning (Gee, 1990). Following from these views, I draw upon methodologies grounded in sociocultural views of learning, classrooms, and language as emerging in interaction, and as contextualized and embodied (e.g. Roth & Huang, 2011; Siry, Ziegler, & Max, 2012). The research I present examines the use of student-driven IBSE instruction as a process that develops in interaction in and with the material, socially, and culturally embedded contexts in Luxembourg primary classroom contexts.

Dialogic pedagogy

My intent with this doctoral study was to provide opportunities for science instruction that created spaces for students to ask questions, and participate in context-rich discussions about their science wonderings and investigations, in a community of learners. In other words, to create classroom spaces that encourage student voice, and to build upon students’ cultural and linguistic resources (Gonsalves et al., 2010). An important theoretical component of the instructional approach at the focus of this research was formulated by drawing upon dialogic notions of discourse, teaching and learning. Bakhtin’s (1981) notion of *dialogic discourse* elaborates on that speech, and communication, are not a simple transmission of words and concepts from speaker to listener. In this transactional conceptualization of speech, the listener is assigned a passive role and is a recipient of the message designed and intended by the speaker. In contrast, dialogic discourse, as theorized by Bakhtin (1981), is a culturally and historically situated act. Listeners, from their own heteroglossic perspectives, assign meaning to utterances. Thus, utterances do not flow from speaker to listener. Instead they are passed between the speaker and the listener, and on both sides of the transaction, meanings are assigned.

To take a dialogic stance is to situate oneself in ways that actively seek out openness, difference and exchange, and to speak and listen in ways that assume there will be difference. It involves positioning oneself to not just to listen, but to receive, hear, interpret, and to then participate by responding from a place of openness. If heteroglossia is a condition of all utterances, then assuming a dialogic stance is a recognition of the multiplicity of voices and diversity, and a purposeful act that works to "overcome a closed, fixed monologic approach to life and replaces it with living in openness to difference" (Bakhtin, 1986, p. 7). To that end, I developed Science Workshop with the aim of positioning both teachers and students in ways by which they could engage dialogically, and thus this study examines the instructional opportunities that position participants to interact in these spaces.

Methodological Considerations

Study design: interpretive, emergent, and multi-layered

Grounded in sociocultural theories of interaction (Rogoff, 2003; Collins, 2004; Sewell, 1999), the qualitative multi-focal research I detail in this dissertation draws upon interpretive qualitative methodologies (e.g., Erickson, 1986; 2013) to examine the use of Science Workshop with teachers, and to analyse the instructional opportunities its use afforded in public school classrooms in Luxembourg. Interpretive research approaches, as explained by Erickson (1986), assume that teaching and learning are "socially and culturally organized" events (p. 120).

The design of this study was emergent. Morgan (2008) explains that emergent research design involves the use of data collection and analytical approaches that change and evolve as the research unfolds and in response to the context that presents itself over the course of research and analysis. The use of an emergent design allowed me to set the course of the research with the overarching aims and research questions, and to adjust them as new opportunities arose. These subsets of studies, their methodologies, and analyses will be presented in Chapters 2, 3, and 4.

This study is additionally multi-layered and multi-logical, meaning it draws from multiple interrelated yet unique theoretical lenses, as will be elaborated in the chapters that follow. Kincheloe and Tobin (2015) explain that one of the strengths of multi-logical research is that it allows the collection of "diverse perspectives on similar events" (p. 7). Working to capture a diversity of voices brought a richness to the analytical perspectives I examined during different phases of analysis, as will be presented in Chapters 2 through 4. By approaching this study through multiple, related, theoretical lenses, I gained not one, but multiple views of the use of this instructional approach. In adopting an interpretive research approach, I was afforded yet another beneficial view as I positioned myself as a co-teacher/participant and researcher in this study. Drawing on these multiple roles and perspectives added an additional layer of insight that I will make clear in the sections to come. First, in the sections that follow, I describe the study timeline, the school contexts, and the research participants.

The Project Timeline

The project involved overlapping layers of implementation. This is presented as a timeline in Figure 1.1. The first phase involved conducting teacher workshops, and then supporting teachers in their use of the program in their classrooms (Figure 1.1 phases 1, 3, and 4). The second phase involved co-teaching using Science Working in a focal classroom for three units of instruction over a six-month period (Figure 1.1, phase 2). The interaction-analysis focused chapters presented in Chapters 3 and 4 are derived from data collected in this focal classroom. When considered together, these layers provided me with feedback and perspectives that allowed for the revision and adaptation of the instructional approach, and for analysis of the instructional opportunities it afforded both through the perspectives of teachers as well as students.

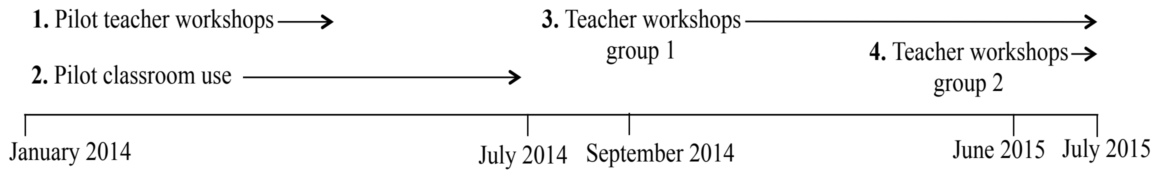

Figure 1.1. The Science Workshop project timeline

The Participants

The data corpus I accessed for the analyses was collected from January 2014 through July 2015. In its entirety, this timeline included the development, use and refinement of Science Workshop by participating teachers and our research team. The participants in each of these respective phases of research and the data corpuses collected from each are detailed in the sections that follow.

My participation as researcher, workshop leader and co-teacher. Throughout the research process, I worked in multiple roles. In this way, I was afforded a radically different view of classroom events from a first-person perspective that allowed me to experience the instruction, and then work to analyse it at a later time (Roth & Tobin, 2004). During the initial phases (Figure 1.1, phase 2) of the project, I co-taught three distinct inquiry-based units of Science Workshop in a pilot classroom in Luxembourg City along with my advisor Professor Christina Siry, colleague Jana Haus, and the classroom teacher. In this role, I was positioned as both a participant researcher and a teacher. This participatory role facilitated my understanding of the instructional approach and how to best adjust it for further use.

This meant that in the teacher professional development workshops I could speak about how to adapt and use components of the instruction based on our experiences teaching with the approach. Additionally, I created audio memos after teaching, and typed up field notes to capture my experiences and reflections (Emeson, Fretz, & Shaw, 2011) and the insights I gained while teaching. I accessed these during later analysis, which afforded me views of my participant perspective and of the interactions in the classroom from multiple points in time.

City Primary: the focal school. Chapters 3 and 4 present analyses that emerged from our co-teaching at City Primary, a mid-size public school, serving approximately 350 children in Luxembourg City, Luxembourg. The school is in a socioeconomically and culturally diverse region of Luxembourg City, and this diversity is reflected in the student body.

Student participants. The focal class in which we co-taught was composed of 16 ethnically, social-economically and linguistically diverse 10-11-year-old students. Over a six-month period, we co-taught three units of Science Workshop (the details of which are further elaborated on in Chapters 3 and 4). The 16 students in the class were plurilingual in a variety of linguistic combinations, not just the three languages of schooling, and they used Luxembourgish in their daily interactions with their teacher. As elaborated on in earlier sections, the Luxembourg national curriculum (plan d'études) specifies that science is taught through the use of German (MENFP, 2011). Thus, the students' language repertoires considered in combination with science instruction in German, and informal interactions in Luxembourgish, created a complex linguistic landscape. This is a crucial contextual component of this study as the majority of students in this class were learning science through a second or third language.

Teacher participants. From January of 2014 through June of 2015, our research team worked with a total of 26 primary school teachers from various regions of Luxembourg (Figure 1.1, phases 1, 3, and 4). 4 of the teachers worked at the European School and 22 taught in the Luxembourg public primary school system. This means that these 22 hold Luxembourg national certification and are fluent in at least the three school languages, Luxembourgish, German, and French. As a group, the teachers varied in prior teacher professional development hours (some had inquiry-based science and project-based learning in their past teacher training programs, others had more teacher-centred training) and also in the number of hours they had participated in professional development (formation continue). Participating teachers received continuing education credits from the "Service de Coordination de la Recherche et de l'Innovation pédagogiques et technologiques" (SCRIPT) for their participation when they attended the full workshop series, taught using the instructional approach in their classroom, provided documentation from their classroom of use of the program (photos, student work and lesson descriptions), completed an instructional survey, and participated in a focus-group interview/resource-sharing meeting.

While Luxembourg is one of the smaller European countries, classroom demographics across the country vary greatly. This is in part due to the fact that it shares borders with three neighbouring countries, Belgium, France and Germany, and in part due to a continuing trend of increasing numbers of non-Luxembourg families establishing residency in Luxembourg. Reflective of this diversity, participating teachers worked with classes of different linguistic profiles, some in more urban schools, and others in more rural villages.

Data Sources

As already introduced, the large data corpus collected for this study is multi-layered in that it incorporates multiple perspectives (i.e. teacher, student, and researcher), which afforded me with multiple perspectives from which to analyse the instructional opportunities created through Science Workshop. To support multi-layered interpretive perspectives on the data, I drew from data resources arranged into two categories. The first were relative to the teacher workshops and the teachers' use of the program in their classrooms. The second were relative to the use of the instructional approach in the focal classroom. Thereby, the two layers allowed for a multi-theoretical approach to analysis (Tobin & Ritchie, 2012) that emerged as the project and analysis proceeded (Morgan, 2008). The sections that follow detail each of the data resources collected.

Data sources relative to the development of Science Workshop. The first phase of my dissertation work involved the development of Science Workshop based on the context I elaborated on in previous sections in primary science education in Luxembourg. This phase involved piloting Science Workshop with a group of teachers at the European School in Luxembourg during a series of professional development workshops. During this pilot phase (Figure 1.1, phase 1), I constructed ethnographic field notes (Emerson, Fretz, & Shaw, 2011) in both written and audio formats before and after teacher workshops in order to record my impressions and to assist in the refinement of the teacher workshop approach.

Data sources relative to teacher workshops and supporting teachers using the approach in their classrooms. The next phase was to conduct teacher workshops and support teachers in using the student-driven instruction in their classrooms (Figure 1.1, phases 2 and 3). The teacher workshops were videotaped (Roth, 2005).

Teacher surveys were administered both at the beginning of a workshop series and at its culmination, and asked teachers to provide information regarding their teaching experience, professional development experience, as well as general characteristics about their current class (number of students, approximate student language profiles).

Participating teachers committed to submitting reflective surveys and student learning artefacts for at least one unit of Science Workshop. After teaching the unit, teachers submitted surveys that detailed the lessons they had taught, and that described the literacy activities they incorporated into instruction. The survey additionally asked them to reflect on the use of students' questions to drive the science inquiry process and also on the use of integrated science and language instruction. At this stage, teachers provided details about their students including languages spoken. They also submitted student-learning artefacts documenting the lessons they taught in the form of science notebooks, sample class lists of questions, worksheets, group posters, and photos of students conducting investigations.

I conducted focus-group interviews with teachers to further analyse their experiences using the student-driven IBSE approach and to ask them to elaborate on their impressions regarding the integration of science and language instruction. These multiple sources of data provided a rich multi-layered view that allowed me to construct implementation cases detailing their use of the program, one of which is presented in Chapter 2.

Data sources from a focal classroom. The second phase of research involved co-teaching three Science Workshop inquiry-based units in a primary classroom in Luxembourg over a six-month period (Figure 1.1, phase 2). Working as a team, my advisor Professor Christina Siry, my colleague Jana Haus, and I co-taught with the classroom teacher. I provide a more detailed explanation of these units and their goals in Chapters 3 and 4. During this process of co-teaching using the instructional approach, teaching and interactions were documented through whole-class and small-group videos. Student learning artefacts, including copies of student science notebooks, and class-produced posters, were collected and digitally archived. Student focus-group interviews were conducted at the end of the first unit. We spoke with groups of two to three students at a time and asked them to reflect on their experiences and impressions participating in student-driven inquiry-based instruction. These interviews were videotaped and transcribed. Additionally, following each instructional period our research team audio-recorded our debriefing sessions. During these sessions, we discussed instruction and next steps, and also our impressions from a research perspective. This allowed me to work to "catch the complexity" of our impressions as both participating co-teachers and researchers (Stake, 1995, p. xi).

Data sources relative to my position in the research. Throughout the entire research period, I maintained a reflective practitioner log in order to be able to view, concretize and later reflect upon my thoughts, impressions and insights about the research process and insights gained along the way. I primarily typed notes detailing my impressions and insights, relative to the different project phases. I also recorded voice memos when leaving research sites, and after teacher workshops, focus groups and planning meetings. Lastly, I maintained journals that allowed me to look back and reflect upon my thoughts at later moments in time. The impressions recorded in these became particularly useful during subsequent analyses. Toward the end of the first year of my doctoral research, the importance of my own perspectives regarding language resource use in a multilingual society were to the analytical perspectives I implemented in analysis. As a result of this reflection, and to further explore my own positions, I embarked on a co-autoethnograpic research project (e.g. Coia & Taylor, 2009; Ellis & Bochner, 2000) to explore my language positions with a research colleague, Jennifer Park. Jennifer was also just finishing her first year of doctoral research, and like me, was working in a multilingual context that she had just moved to. We implemented a process of self-reflection, and analysis, that led to a collaborative autoethnographic exploration of our language positions and histories, to culminate in a critical examination of how these intersect within our respective research endeavours. While this exploration and self-analysis provided key insight that lead to the research I present here, it is not included in this dissertation. Further details about the research process and our findings are elaborated on in Park and Wilmes (2017).

Data Analysis

The data analysis performed for the research I report herein followed emergent, on-going rounds of iterative analysis (Tobin et al., 2005), and involved the purposeful selection of subsets of data resources from the larger data corpus for analysis relative to the research questions and foci that emerged during the different phases of research (Morgan, 2008). When considered as a cohesive body of research, the three analyses I present in Chapters 2 through 4 provide interrelated views of the inquiry-based science instructional approach.

Key Considerations

Working with Research Participants

The research detailed herein was approved by the University of Luxembourg's Ethics Review Panel, and therefore fell under the regulations of the University of Luxembourg's policy on ethics in research. As such, all research protocols were subject to ethics review, and received approval prior to the start of data collection in the fall of 2013. In accordance with this approval, consent for all participants was obtained. A detailed description of the research project, its intent, and the forms of data that would be collected and analysed was described to teachers, students, and parents before asking for their consent and/or assent to participate. Consent and assent forms were provided in both French and German, to ensure readers' access to the information contained on the consent/assent forms. Participants were allowed to withdraw from participation at any stage during the research period without penalty. For all students, as they were under the age of 18, permission was obtained as both consent from their guardian(s), and as assent on their own behalf. This provided a space for students to voice their willingness, or not, to participate in the research (Cowie, Otrel-Cass, & Moreland, 2010). All information was explained orally so that students understood the research process, and how to withdraw from participation at any point. Teachers involved in this study, signed consent forms allowing for collection and use of survey information and video data sources in research presentations and publications. In this way, all participants willingly and knowingly consented, or provided assent, to participation in the research. A sample assent form provided to students, and sample consent form provided to teachers are included in Appendices A and B.

Language Considerations

This study was conducted in multilingual contexts (classrooms, teacher workshops and focus-group sessions) with plurilingual participants. Language use, communication resources, and voice were crucial components in every aspect of this study. In teacher workshops, the working languages were Luxembourgish, German and English. In classrooms, we spoke Luxembourgish and German with students. Among our research team we spoke English and German. This is reflective of everyday life in Luxembourg. It is typical for all of us, and by *us,* I mean all of us (students, parents and educators) in Luxembourg, to speak at *least* two or more languages every day, often in the same context, and even often in the same interaction. This places language, and having a firm grasp of the position and nature of language (voice), high on the list of factors to consider when conducting research in Luxembourg. Herein, I describe how I approached working within these multilingual contexts with plurilingual participants and colleagues.

Language considerations when working with participants. At the beginning of teacher workshops, and when first working with a class, our research team would introduce each of our language repertoires. The description I would give of myself in Luxembourgish at the time was something like this, "Hello, my name is Sara. I am American. I moved here to Luxembourg three years ago, and now Luxembourg is my home. I speak English, and a little bit of Luxembourgish and a little bit of German." Each of us would explain who we were, which languages we were most comfortable using, and then we collectively explained, "You may speak to us in the language of your choice." This created spaces where there was a movement back and forth between semiotic resources (verbal, gestural, etc.) as needed to facilitate communication and understanding.

Language considerations when working with data sources. As a precursor to the analysis, which I detail in Chapters 2, 3, and 4, I conducted repeated recursive cycles of immersion in the multiple forms of data. This allowed me to become familiar with the flow through workshop sessions, and classroom sessions, and then to embark on a more detailed analysis targeted to the questions that emerged. Throughout analysis, data sources were kept in their their original languages (i.e., the language in which the data was collected). All first, and often second and third, viewings of video data were conducted with the sound turned off. This approach was crucial in that it afforded me the opportunity to background language and focus on other factors that were engaged in classrooms and during workshops. During these and subsequent analytical phases, I recorded research notes and analytical memos in English in Transana and in Word documents. As I conducted subsequent, more in-depth layers of analysis, and zoomed in on portions of the data corpus, I transcribed interactions, student work, or interview excerpts in their original version/language. Transcriptions and translations into English were performed and subsequently verified by a second, and sometimes a third, research colleague with a high level of proficiency in the language(s) being used in the data source. In later stages of analysis, once I determine an episode or learning artefact was essential to a research manuscript or presentation, the episode or artefact would be translated into English. This was done for publication and presentation purposes. Throughout analysis I worked to compare my transcriptions, translations and interpretations with research colleagues fluent in the language(s) in which I was working.

Research validation processes

The study presented herein draws upon interpretive methodologies (Erickson, 1986) to investigate the use of Science Workshop, and IBSE instructional approach, with teachers and in classroom contexts. In adopting such an interpretive approach in this study, I worked through the multiple phases of research with an attunement to "the dialogical context of human understanding" (Angen, 2000, p. 384) and I acknowledge that I cannot remove my own "intersubjective involvement with the lifeworld" (p. 384) from the study. Because of this, I incorporated validation processes throughout all phases of research in order to work toward both *ethical* and *substantive* validation in recursive cycles (Angen, 2000, p. 387). Ellingson (2011) explains that *ethical* validation involves undertaking research in such a way that it has practical value, generative promise, is transformative and takes a non-dogmatic approach in reporting findings. Its compliment, *substantive* validation, involves processes that challenge the researcher to work toward doing justice to the complexity of the topic of study. Ellingson (2011) elaborates on that one way to undertake a substantive validation process is to include multiple views in order to assure a one-sided perspective has been avoided. It also challenges the researcher to be self-critical throughout the research in ways that reveal the researcher's position relative to the study (Alcoff, 1994). Throughout the research, I present in this dissertation, I incorporated on-going validation processes in order to ensure substantive and ethical validation in order to work toward validation "across the continuum" of research approaches that I draw upon (Ellingson, 2011, p. 601). I further elaborate on both the substantive and ethical validation processes that I incorporated in the integrated discussion in Chapter 5 in conjunction with a presentation of the understandings revealed through this study.

Overview of the Dissertation

This dissertation is a multi-layered study (Tobin & Ritchie, 2012) of the instructional opportunities created through the use of Science Workshop in multilingual classrooms in Luxembourg. Guided by the research questions and by theories introduced earlier, an emergent analytical process (Morgan, 2008) allowed space for me to conduct analysis on subsets of questions, and to zoom in (5, 2004) on phenomena that emerged during analysis. In this way, the research process was emergent and unfolded over time. More importantly, when brought together as a whole, the multi-perspective analyses I present here provide different views of the

Science Workshop (Kincheloe & Tobin, 2015) that speak to the overarching research questions presented earlier.

This dissertation is written in *manuscript-style*, also referred to as a *dissertation-by-publication*. Each of the chapters that follow has been prepared for publication, one as a book chapter and two journal manuscripts. For this reason there are sublet formatting differences among the chapters.

In this introductory chapter, I first present the context and form of the overall study. Subsequent chapters will present several qualitative analyses that draw from sociocultural lenses and methodologies which afforded the opportunity to present the multiple analyses included herein as they emerged during the research process, and as they led to emergent, contextualized subsets of questions. Considered together, the multiple analyses presented in Chapters 2 through 4 provide a multi-layered view of the instructional opportunities created using Science Workshop, and IBSE instructional approach in Luxembourg primary classroom contexts. To conclude, I present an integrated discussion in Chapter 5, that elaborates on the impact of this study for science instruction in Luxembourg specifically, and more generally, the findings that emerge relative to student-driven IBSE, which positions students to use their voices as resources when learning science in multilingual contexts. The structure of the chapters that follow is as such:

Chapter 1 laid out the foundation of this study with a detailed explanation of the context of the study and the inquiry-based student-driven instructional approaches at the focus of this study. I explained on the qualitative interpretive methodologies employed, and elaborated on sociocultural theories, which ground the analyses in subsequent chapters. I provided an overview of the study design, theoretical grounding, and specifics regarding the participants with whom I conducted the research, to set the stage for the analysis I present in the next chapters.

In Chapter 2, I present a detailed examination of the teacher professional development component of the study. The key components of this program and support mechanisms that were identified through the process of working with teachers are discussed. An implementation case is presented that illustrates the nature of heteroglossic instructional spaces that can be created through the use of the student-driven inquiry instruction.

Next the dissertation transitions to interaction analysis in a focal classroom in which we co-taught using the Science Workshop approach. In Chapter 3, a methodological lens of Interaction Ritual Theory (Collins, 2004) is applied to understand how the ritualized instructional components of Science Workshop created spaces for interaction rituals to form on the micro-level in interaction, as students worked in small-groups during student-driven science investigations.

Chapter 4 presents an interaction analysis of semiotic social spaces in and surrounding the use of student science notebooks in this same focal classroom. Multimodal interaction methodologies are used to afford views of the pedagogical potential of science notebooks in this multilingual classroom, when used in conjunction with IBSE instruction.

In conclusion, Chapter 5 ties together the research project as a whole through an integrated discussion, and elaborates on the heteroglossia and understandings revealed in analysis. In this last chapter, cumulative findings presented in analysis in Chapters 2, 3, and 4 relative to IBSE use in Luxembourg primary classroom contexts are elaborated and understandings that arise from the study as a whole are detailed.

The chapter closes with a discussion of the implications of this dissertation for theory, research and teaching, and concludes with suggestions for future research.

CHAPTER 2

SCIENCE WORKSHOP: LET THEIR QUESTIONS LEAD THE WAY[4]

Abstract

Science Workshop is an integrated science and language literacy program piloted and implemented by primary school teachers in multilingual classrooms in Luxembourg. Grounded in theories supporting the integration of inquiry-based science education and language learning, Science Workshop consists of a teacher professional development program and instructional approach that engages students in inquiry arising from their questions in meaningful learning contexts. In this chapter I detail the strategies and resources used in Science Workshop, a science program which is attuned to student's voices as they question and conduct science investigations, and show how the program supported teachers in implementing integrated science and language literacy instruction at the primary level. Specifically, I discuss how Science Workshop supported the formation of heteroglossic language learning spaces within the confines of a system guided by monoglossic language policies.

Keywords: inquiry-based science education, integrated science and language, teacher professional development, student voice, heteroglossic learning spaces

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Project Context

The Science Workshop Teacher Professional Development (TPD) Project arose from a multi-year research program supported by Luxembourg's national science funding body, Fonds National de la Recherche (FNR), and the University of Luxembourg. The project details I share in this chapter arose from our team's work during the full-year program pilot (2013–2014), and the first full year of program implementation (2014–2015). During the pilot phase, our University-based TPD coaching team co-taught several Science Workshop units in a multilingual class- room in a mid-sized city in Luxembourg. In this chapter, I draw from both our own classroom experiences piloting the project, and the data resources from the 20 plus teachers who successfully implemented Science Workshop in their primary school classrooms to show how this model successfully supported teachers as they adapted and used the program.

Luxembourg's Language Landscape

The language landscape in Luxembourgish schools, as in many countries, is complex. Teachers are fluent in at least the three languages; Luxembourgish, German, and French. The student population in Luxembourg is increasingly diverse and multilingual with 49 % being non-Luxembourgish (MENJE, 2016). This means that many students speak at least one additional non-national language at home, while being schooled in the three national languages. The teachers participating in this program implemented Science Workshop at a range of grade-levels (ages 5 through 12 years-old) in public primary schools that utilize Luxembourg's national competency-based curriculum. This national curriculum supports a trilingual program with students conducting classroom business in Luxembourgish, and learning German and French literacy as isolated school subjects at the primary level. In this sense, the Luxembourgish language approach is monoglossic, which, as described by

García (2009), are educational settings in which "each language is carefully compartmentalized" (p.115). Additionally, from 7 years of age students learn science *through* the German language. Since German is a second or third language for many students (Luxembourgish or another language being their first), this means that almost all of Luxembourg's student population learns science at the primary level through a second or third language. These contextual factors taken as a whole underscored the need for a program that supported teachers in a) integrating science and language instruction, and b) teaching in ways that flexibly support students who are learning both science and an additional language (in this case German) within what can be considered a 'traditional' trilingual education system.[5] In the sections that follow, we detail the approach we used to prepare teachers to address both language learning and science learning needs in synergistic ways.

Project Development

Science Workshop is a TPD model and science instructional program developed by our science education team at the University of Luxembourg. The team consisted of a university professor and two doctoral students, all three of whom had extensive experience working with primary age students and developing science education programs. The development of Science Workshop took place following what we learned about science and language instruction in Luxembourgish primary schools during the implementation of the Fibonacci Project (www.fibonacci-project.eu) in Luxembourg from 2010 to 2013. During this time, our team assisted in the support of

[5] While the linguistic landscape of Luxembourg is unique in the trilingual demands it places on students, it is similar in many ways to those found in varying degrees in every country. Whether a student is learning multiple languages, or one language (keeping in mind that science is also a culture and language itself (Cobern & Aikenhead, 1997), Science Workshop can support teachers in the integration of science and language in ways that lead to both language and science learning, even in schools with apparently 'homogeneous' language landscapes.

inquiry science instruction in several schools in Luxembourg, and gained first- hand experience through observations and discussions with teachers that led us to identify central facets of a science instructional program that could address key language and science instructional needs. These facets, aligned with the needs described by teachers, formed the backbone of the program and provided the theoretical foundations for the program we developed, Science Workshop.

Science Workshop consists of a teacher professional development program and instructional support grounded in three key theoretical features arising from practices science and language education research has shown can be effective, namely:

(i) The use of students' questions to drive the inquiry-based science learning process (Exploratorium, 2006; Gallas, 1995; NGSS Lead States, 2013),

(ii) The integration of language literacy and inquiry-based science instruction (Cervetti et al., 2012; Lee & Fradd, 1998; Stoddart et al., 2010; Varelas & Pappas, 2013), and

(iii) The construction of informal heteroglossic language spaces (Flores & Schissel, 2014; García, 2009) as places for students to flexibly learn both communicative competencies and science both in and through a second or third language.

I elaborate the theoretical underpinnings of each of the three key features in the sections that follow and describe how each plays a role in the Science Workshop professional development and instructional support program.

Students' Questions Drive the Inquiry Process

Over a decade of education research has established the merits of inquiry-based science education (IBSE) and its positive influence on student science learning (Minner et al., 2010; Rocard et al., 2007). IBSE is rooted in socioconstructivist theories of learning and engages students in actively making observations, posing questions, planning investigations, interpreting data and communicating results to diverse audiences (Minner et al., 2010; National Research Council, 2012; Worth et al., 2010). Research has established that IBSE is particularly valuable in multilingual contexts, such as encountered in Luxembourg's schools, because students construct meaning as they experiment, question, and communicate, and thus IBSE provides a rich and authentic context for language development (Haneda & Wells, 2010; Lee & Fradd, 1998).

The inquiry instructional model employed by Science Workshop first engages students with a phenomenon, and from this initial engagement students are asked to generate questions. These questions are then used to lead students into deeper inquiry (Exploratorium, 2006; Gallas, 1995; van Zee et al., 2001). Eliciting students' questions in this way accomplishes two goals simultaneously. First, it engages students in a key process of scientific inquiry (NGSS Lead States, 2013). Second, it opens the door for students to voice their wonderings and interests. This is valuable for students in that their voices – and their unique interests, worldviews, and perceptions – are revealed. This is at the same time valuable for teachers in that they are afforded a view into their students' curiosities and are then able to use this information to tailor science and language instruction.

Instruction Integrates Inquiry-Based Science and Language Literacy

Research has established that inquiry-based science instruction that integrates language literacy skills (reading, writing, speaking and listening) presents synergistic opportunities for students to learn both language literacy and science (Cervetti et al., 2012; Stoddart et al., 2002). IBSE supports this in that students construct meaning as they experiment, question, and dialogue, and write about their inquiry experiences. Thus, they are provided with a rich and authentic context for literacy development (NRC, 1996; Lee & Fradd, 1998). Science Workshop utilizes this approach in that it incorporates complex and appropriate literacy learning tasks embedded within context-rich inquiry science lessons.

Heteroglossic Spaces Allow Students to Flexibly Utilize Communicative Resources as They Engage in Inquiry-Based Science

Today, many bilingual and multilingual primary school programs in Western cultures remain monoglossic in nature. This means that multilingual students are, more often than not, required to use one language at a time in learning settings (García, 2009). This view of multilingualism, García explains, views each language as a discrete separate entity and values the fluent speaker of the language as the desired learning goal. For example, in Luxembourg students who speak Portuguese at home and who attend Luxembourgish primary schools will find that at the age of five they are expected to speak only Luxembourgish in their daily classroom learning routines. When they reach first grade, they begin to learn German literacy as a subject, and one year later French literacy. Rarely are French, German, and Portuguese used in systematic synergistic ways to help the students learn any of the other languages. They are judged throughout their schooling relative to fluent French and German speakers. This is a monoglossic school environment. The work of several education and linguistics scholars including García (2009) have drawn attention to the fact that this monoglossic approach to multilingualism does not reflect the fluid, flexible ways in which students draw on a mixture of semiotic resources during their time outside of school. In contrast to monoglossic learning spaces, heteroglossic learning spaces, in which students are able to flexibly use semiotic resources fluidly without regard to bounded languages as they learn, are more beneficial for the multilingual students' educational career (Flores & Schissel, 2014; see also Blackledge & Creese, 2014).

The concept of heteroglossia is derived from Bakhtin's (1981) notion of multivoicedness. At its core, it means the valuing of more than one 'voice' speaking at the same time either within a single language or a text.[6] In our work we take heteroglossic to mean spaces within which students and teachers are able to incorporate more than one voice, more than one language, or more than one semiotic resource for expression, communication and learning. We designed Science Workshop to support teachers and students in engaging in learning that draws upon, and makes intentional space for multivoicedness (Bakhtin, 1981) as students synergistically learn both science and languages. For this reason, Science Workshop is built upon a pedagogical stance that incorporates instructional approaches that allows students to draw from their full linguistic repertories (Otheguy, García, & Reid, 2015). Additionally, as was shown in the work of Flores and Schissel (2014), we feel that the inclusion of heteroglossic spaces in instruction is a way for educators to carve out spaces that value students diverse resources as they learn, and that push back at national education schemes aimed at producing monoglossic speakers of nationalized languages. In the sections that follow we describe the Science Workshop TPD program and its use in classrooms in Luxembourg.

Teacher Professional Development Model

Based on practices that have been shown can be effective in language and science education professional development (Lee, 2004; Loucks-Horsley et al., 2009) the TPD program involved a combination of three key features; a teacher workshop series,

[6] For a more complete discussion of Bakhtin's conceptualization of *heteroglossia* see Blackledge and Creese (2014).

material support, and on-going coaching support. An overview of a single year of the TPD program is shown in Figure 2.1. Next, I describe each of these features.

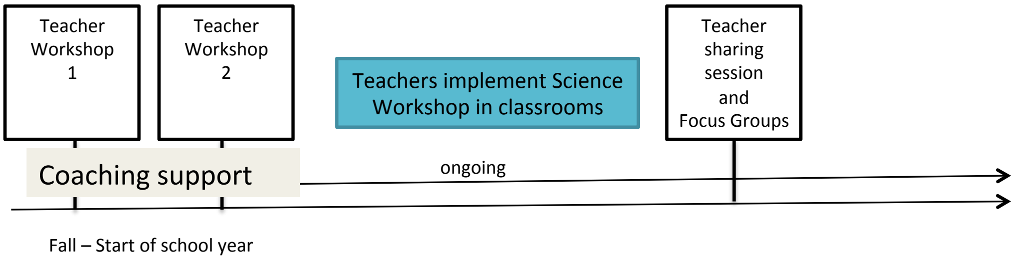


Figure 2.1. Science workshop's year-long teacher professional development (TPD) program

Teachers participated in two half-day sessions in the beginning of the school year over the course of 1 week. The purpose of the workshops was to familiarize teachers with the theoretical underpinnings of the program, to allow them to experience inquiry rooted in questions first-hand, and to prepare them to use this learning approach in their classrooms. A brief overview of each of the two three-hour days is shown in Figure 2.2. The two topics of inquiry we used in the workshops were worms and snails. These subjects were chosen as they are typically taught in Luxembourgish primary school classrooms, and are easy to obtain in our environment. We chose to work with topics the teachers typically teach using transmission-learning based activities in order to provide teachers with the opportunity to compare how they typically teach these topics with the Science Workshop approach.

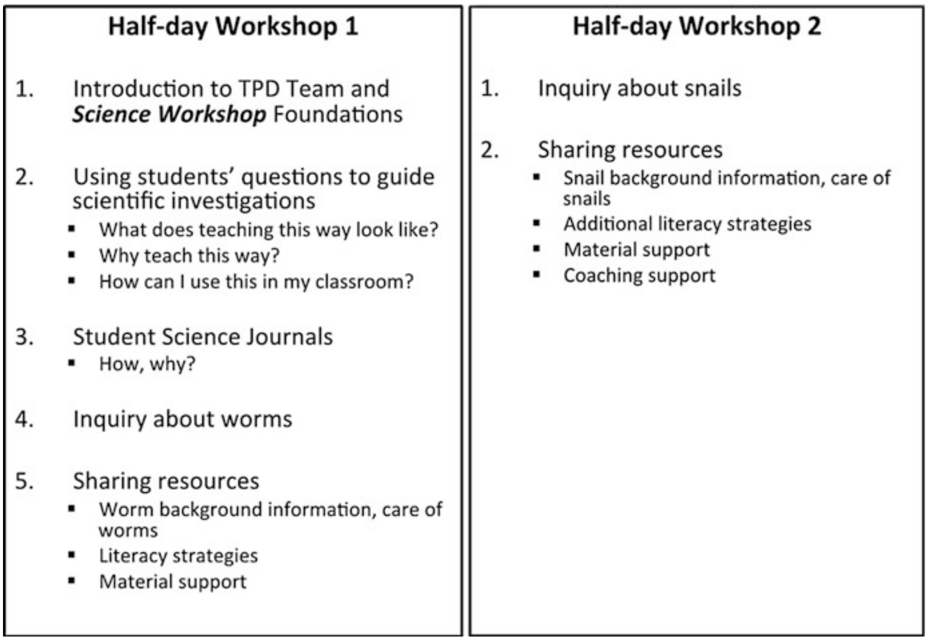


Figure 2.2. Overview of teacher workshops

Inquiry science driven by students' questions

The science inquiry instructional model that serves as a foundation for the Science Workshop was derived from a conceptual model developed for The Fibonacci Project (www.fibonacci-project.eu), conducted Europe-wide from 2010 to 2013. After its implementation in Luxembourgish schools, we adapted it based on instructional guides for inquiry based on students' questions developed at the San Francisco-based Exploratorium (2006). We emphasized to the teachers that inquiry is driven by the interests and questions of the students and as such focuses specifically on their situated, contextual view of the topics being explored.

Integrated Inquiry-Based Science and Language Learning

Within each stage of inquiry, literacy tasks were integrated that served as instructional opportunities. Each was strategically selected to start with a more context- embedded less-linguistically demanding task. These were then followed by less context-embedded, more demanding tasks. For example, teachers were asked to first discuss verbally with a partner what they were wondering about worms. Next, they were asked to individually write a list of questions in German about worms in their science journal. In this way, the person doing the questioning is first provided with social support (the ability to speak informally with a partner) and then is asked to complete the more linguistically demanding task (writing the questions in German in the science journal). This approach, derived in part from the theoretical foundation described by linguist Cummins and illustrated in Cummins' Matrix (1984) shown in Figure 2.3, is one way to visualize the complexity of language tasks.

Science Workshop integrates literacy tasks in such a way so that they start out less demanding (in both a language and science sense), and then shift to more demanding tasks as students build language skills. Cummins' matrix provides a way to conceptualize these aspects of integrated literacy tasks, and helps teachers contemplate ways to build and extended students' science and language skills across tasks.[7] Examples of how these tasks can be conceptualized a long a continuum in order to support growth in language ability and science understanding are shown in Figure 2.4.

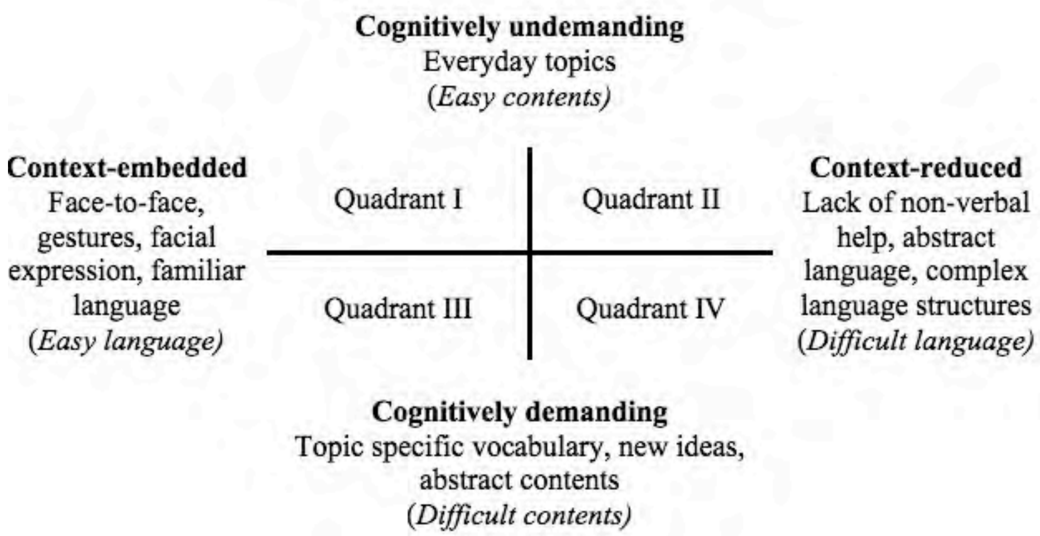


Figure 2.3. Theoretical foundations of Cummins' (1984) task difficulty matrix

[7] For an in depth discussion of the matrix see Cummins (1984).

Student Science Journals

A key feature of the Science Workshop program is the use of student journals, also referred to as science notebooks (Chapter 4). These journals, when used as an informal writing tool, place value on student voice and allow students to choose how and in which language(s) they record entries. As such, the science journal acts as a space in which students can flexibly and fluidly record questions, wonderings, data, and conclusions in ways that utilize the full complement of semiotic resources in their communicative repertoires. I share examples of how the journals were used in classrooms in the implementation case presented in the following pages. During the TPD workshop we showed teachers how to set up the notebook provided general guidelines for using them with students.

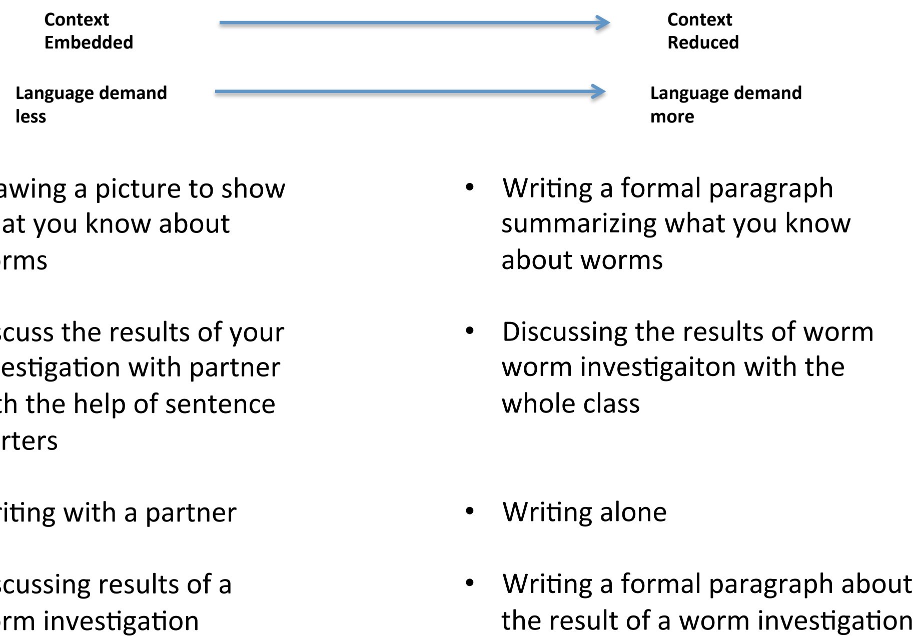


Figure 2.4. Task sequences embedded in science workshop

Science Materials

Following participation in the workshops, teachers were provided with kits to support two units of inquiry (one on the topic of worms and one on the top of snails) in their classroom. Each kit contained basic tools – magnifying glasses, rulers, pipettes, spoons, paper trays, cups, containers, coloured paper, a class set of blank notebooks, a worm farm and a terrarium in which a snail habitat could be built. The idea behind the kit contents is that first, each student is provided with a science journal, and second, that the kit be stocked with items that are easy to obtain so that they can be used for subsequent inquiry investigations and easily restocked.

Coaching Support. For the duration of the yearlong project, members of the science education professional development team at the University of Luxembourg provided ongoing coaching support for participating teachers. Members of the team have extensive experience teaching inquiry in primary classrooms, supporting teachers in using integrated science and language literacy programs, and using Science Workshop in Luxembourgish primary classrooms. The opportunity for coaching support was introduced to teachers in the initial workshop session. Teachers were invited to contact the PD team when they had questions, or if they would like help – even if this meant just an additional set of hands – while using Science Workshop in their classrooms. Following this invitation, teachers contacted the support team when they desired and asked questions as varied as, 'How do I deal with the noise in my classroom?' to 'Do you know where I can find additional materials?'
The TPD team held focus group interviews once all teachers had the opportunity to use Science Workshop in their classrooms for the purposes of checking in with teachers as to how the implementation was progressing, and to support them in further implementation of additional inquiry activities. These focus group interview meetings were key in the sharing of support and resources as teachers shared student

work, ideas, and asked questions of each other and the TPD team, reinforcing their resource network for the use of the program.

Project Participants

Over the course of 2 years (two 1-year cycles), we worked with 22 teachers from various regions of Luxembourg. Teacher recruitment was conducted through several established teacher professional development structures. We advertised the project 6 months prior to the start of the first year with the national teacher professional development department, Le Service de Coordination de la Recherche et de l'Innovation pédagogiques et technologiques (SCRIPT), with a science communication website run by the FNR (www.science.lu), and through direct emails to teachers. The result was a group of teachers, 20 % with whom we had previously worked, and 80 % who were new to our programs and us. All twenty-two participating teachers taught in the Luxembourgish public primary school system. This means that they hold Luxembourgish national certification and are fluent in at least the three official languages; Luxembourgish, German, and French. As a group, they varied in the types of training programs they had completed (some had inquiry- based science and project-based learning in their teacher training programs, others had more teacher-centred training) and also in the number of hours they had taken TPD. Participating teachers received continuing education credits for their participation when they attended the full workshop series, taught the program in their classroom, provided documentation from their classroom of use of the program (photos, student work, lesson descriptions), and participated in a focus-group inter- view/resource-sharing meeting.

While Luxembourg is small in size, the demographics of classrooms across the country vary greatly. This is due in part to the fact that it shares borders with three neighbouring countries, Belgium, France, and Germany and partly because of a continuing trend of increasing numbers of non-Luxembourgish families establishing residency in Luxembourg. Therefore, each participating classroom had a different linguistic landscape.

Classroom Implementation

Teachers documented their use of Science Workshop through the writing of descriptive lesson logs and photo documentation of students' investigations and science journals. To illustrate how Science Workshop was adapted and used in the classroom, we present below an *implementation case*. An implementation case is a description of the use of Science Workshop in a classroom that weaves together details of instruction along with teacher's reflective comments stemming from surveys and group interviews. Implementation cases are derived from on purposeful sampling methodologies specifically the concept of index cases (Patton, 2015), which allow for the documentation of novel practices or occurrences. In this context, the development of implementation cases allowed the construction of cases of teacher classroom instructional practices using the Science Workshop approaches. The development of implementation cases allows us to show both, how Science Workshop was used in the classroom, and at the same time represent the implementing teacher's thoughts and impressions about the program's use. Because of space limitations, I present one implementation case in the sections that follow. I share Tristan's[8] case because it shows in general, how he adapted the Science Workshop program to provide integrated science and literacy instruction for his students, and in particular, how heteroglossic language spaces were created through the use of the student science journal.

[8] All participating teachers and students have been assigned pseudonyms.

Tristan's Implementation Case

Classroom Context. Tristan teaches 10–11-year-olds in a primary school on the outskirts of Luxembourg City, the capital of Luxembourg. In the year he participated in Science Workshop, his class consisted of 10 students. Eight of the students spoke Luxembourgish at home. The majority of his students also spoke at least one additional language at home such as Portuguese, Polish, English, French or German. The first time Tristan used Science Workshop he explained that he implemented the activity sequence exactly as he experienced it during the workshops, and simply adjusted the activity frames to a level appropriate for his students. The lesson sequence used by Tristan was as follows:

- **Activity 1** – Quick Write. Write ten words that come to mind when you think about worms. Draw a worm.
- **Activity 2** – Observe a small group of worms. Record what you see (Was ich sehe) and questions you have (Ich frage mich).
- **Activity 3** – Creation of a class list of questions. Questions marked with 'E' the class believes can be explored using an experiment.
- **Activity 4** – Design an investigation to explore a question about worms (Würmer Untersuchung). Record your question, prediction and materials you will need.
- **Activity 5** – Document your worm investigation: Explain a. What we did; b. What happened – draw a picture of your investigation, write about your investigation, take a photo.
- **Activity 6** – Write to someone you know explaining what you found out from your worm investigation.

Figure 2.5 Tristan's lesson sequence

Before beginning the inquiry about worms, each student set up a science journal complete with a table of contents, glossary, dated entries, and blank pages to record investigations. As will be explained in the sections that follow, use of the science journal was a key tool for Tristan's students with several important implications for student voice, integrated science and language learning, and the creation of heteroglossic spaces.

For their first activity, students wrote and drew what they knew and thought about worms. Then, while working in pairs they observed a small container of worms selected from a larger worm farm set up in their classroom. In their science journals students recorded, “Was ich sehe” (What I see) and “Ich frage mich” (What I wonder). It is during these first two activities that the voices of the students begin to emerge. Figure 5 presents sample work from two students, Olivia and Jana, who worked as a pair. We share the work of Jana and Olivia because of their interesting use of languages. As the lower half of Figure 5 shows, Jana (right) consistently used German when writing in her science notebook. Olivia, on the other hand, alternated between French and German. Tristan explained to us that Olivia is a student who has lived in Luxembourg for 2 years, and who identifies as Portuguese. As far as Tristan is aware, she speaks Portuguese at home. In class, she expresses herself in French, and will not converse in Luxembourgish nor in German. But, she is able to comprehend all German and Luxembourgish that is spoken to her.

The first two activities are structured in such a way as to draw upon the contextualised, grounded-in-experience, personal observations and wonderings of each student. In this way, we begin to see the unique perspectives, resources, and understandings (Siry et al., 2016) each student brings and how these emerge in their science journal entries. It is additionally interesting to note, which languages they choose to record different aspects of their multiple entries. Jana records both Activities 1 and 2 in German, while Olivia records the activity title, “Würmer” and directions “(10 Wörter)” in German, while recording her observations in French. Most likely this is because the title and directions were provided by the teacher, while the remaining entries are her original thoughts arising from her inquiry experiences. In comparing these two sets of entries, we see how students’ perspectives and language choices within the same activity differ, and thus heteroglossic language spaces were created within the activity structure Tristan provided.

Figure 2.6. Olivia and Jana’s group work

Next, Tristan led a whole-class discussion (Activity 3). In collecting students’ individual question in this way, the voices of each student are shared and recorded as a collective class document. This individual-collective dance that occurs as the unit progresses plays a role in supporting students in using the language of their choice, while transforming their responses into the language targeted for instruction – in this case German. Following this activity, the class identified which questions they might investigate using a scientific experiment. Tristan asked each pair of students to investigate a different question. Using an investigation template first shared in the teacher workshop, students designed an investigation to, as Tristan explained, “help them find answers to their questions". In Activity 4, students developed an investigation plan, complete with materials needed, and next (Activity 5) documented using different modes (written, drawn, photo documentation) what happened when they conducted their investigation

We return to a comparison of Olivia and Jana's science notebook entries shown in Figure 2.6. In Activity 4, Jana records her question, "Wie lang kann er werden?," (How long can they – the worms - be?) in German. This same question is also in Olivia's notebook, in German. The language(s) Olivia chooses to use for the rest of her entries differ from Jana's choices. As her entries for Activities 4 and 5 reveal, scientific terms provided by the teacher "vorhersagen" (predict) and "beobachten" (explain), are written by both students in German. In the concluding exercise (Activity 6), students are asked to write a letter to a friend or a parent explaining what they learned, Olivia chooses to write in French. Thus, Olivia has effectively utilised her student journal as a heteroglossic space in which she freely alternates her use of French, and German, as well as sketches and photos to document her science experience. In this way, she draws upon her diverse linguistic competencies (Otheguy et al., 2015) and several different modes (Varelas & Pappas, 2013) to represent her inquiry experience.

When asked about the integrated language and science approach used in Science Workshop, Tristan shared, "It's quite nice to use the language in a different way." For (the students) it's not really doing work but more like having an experience with worms. Tristan went on to explain that "because the questions, and the development of the experiments and their results are recorded, you can promote linguistic knowledge in science teaching." Therefore, "linguistic learning can quite easily be integrated into science classes."

Regarding the use of students' questions to guide inquiry, Tristan explained that he finds this to be a very authentic way of learning science, as it calls students to think about their own questions and to find solutions to their questions. He noted that his students were very motivated to turn to additional sources beyond the classroom to answer their questions, and asked him if they could do their next science unit about nutrition in the same way, starting with their questions.

Program Outcomes

In this section, I elaborate program outcomes relative to the instruction teachers implemented in their classrooms, and relative to the teachers' perspectives on both question-driven inquiry and integrated science and language learning. In elaborating these outcomes I will highlight both the successes achieved through the use of Science Workshop, and the associated challenges teachers faced.

Classroom/Instructional Outcomes

One of the most apparent features of Science Workshop was the relative ease with which it was adapted for use in primary classrooms. I feel confident saying "ease" in that the participating teachers worked in a wide range of grade-levels (K-6) and each was able to immediately adapt and use the workshop in their classrooms. These adaptations took different forms in each of the participating classrooms. For some, this meant partnerships were formed between pairs of primary teachers who co-taught, meaning one teacher focused on the language instruction while the partner focused on the science instruction. In others, the adaptation took the form of one teacher planning both language and science integrated lessons for the first time. Teachers working in classrooms with younger students focused on ways to introduce students to basic literacy through their questions and investigations (Figure 2.7), while teachers working with older students adapted the resources provided to meet their students' literacy levels. This speaks to the ability of Science Workshop to provide a framework for integrated science and language instruction adaptable to varying levels of instruction.

Teacher Outcomes. Concluding their participation in the program, teachers completed open-ended surveys and participated in focus-group interviews. These revealed teacher perspectives after their use of the program.

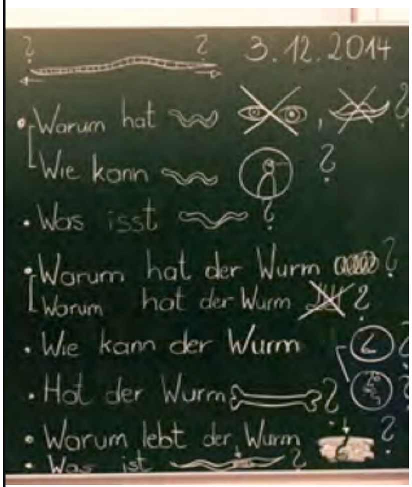
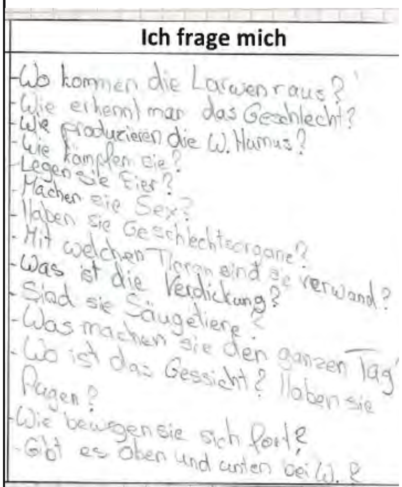
<table>
<tr><th></th><th>6 year-olds classroom</th><th>10 year-olds classroom</th></tr>
<tr><td>Students' questions</td><td>
</td><td>
</td></tr>
<tr><td>Adaptations</td><td>Students talk about their questions in small groups and then share questions in a whole-class discussion. The teacher records questions on the blackboard integrating images so that the focus is on question verbs and question stems (warum? wie? was?/ why? how? what?)</td><td>Students individually record questions in their science notebook while working in pairs. Next they share questions in a whole class discussion and discuss which can be investigated.</td></tr>
</table>

Figure 2.7. Adaptations of a science workshop activity across grade levels. A common activity, 'Formulating questions', was adapted for use at two different grade-levels.

Relative to teachers' perspectives of integrating science and language/literacy learning, teachers shared that the integration of language and science instruction occurred smoothly as it arose from the design of the embedded tasks that were rooted in students' experiences while investigating. For example, when asked, "Did you integrate science and literacy learning?" one teacher responded… "Of course, it was a natural fit…". This shows that the use of this program demonstrates how language learning and science learning go hand-in-hand.

Relative to the use of students' questions as the driver of inquiry, teachers revealed that this method of instruction, increased student engagement in science lessons and motivation. This was apparent in students' enthusiasm in conducting the experiments, in students' increased rate of asking questions when conducting investigations, and their investment in finding answers to their questions. Teachers also shared that this approach gives student's voice a place in the science curriculum in meaningful ways.

Relative to the formation of heteroglossic instructional spaces, analysis of students' science notebook entries (Figure 2.6), coupled with teachers' comments during focus group interviews, showed that students self-selected to use languages other than the language of instruction at different points during different activities. Teachers also reported, and it was observed during classroom observations, that different groupings of students utilised different languages – other than German – at different points in the inquiry process. This indicates that heteroglossic spaces, while small and intermittent, existed and were used by the students.

Conclusions and Implications

Based on the pilot and field-testing, the following key conclusions can be drawn about the use of Science Workshop:

Science Workshop supports locally contextualised adaptable/flexible integrated science and language literacy instruction

As we saw in the representative implementation case, through the use of students' questions, teachers in Luxembourg across a range of grade-levels were able to design and implement integrated science and language instruction that was locally contextualised and connected to students' personal contexts in meaningful ways. This is particularly notable in an era of science education that tends to promote the adoption of science programs that require significant material investments and the purchase of programs produced and sold by major publishing houses. Science Workshop, in contrast, provided for instruction across various grade-levels in flexible, locally contextualised ways. It accomplished this as it tapped into and utilised the cultural and linguistic resources of the students, and used these "funds of knowledge" (Moll et al., 1992) to provide interesting, engaging instruction.

Science Workshop helps create heteroglossic spaces within traditionally monoglossic learning environments

Monoglossic multilingual programs that allow one 'voice' or that value the use of one national language at a time can harm students' language competency development (Otheguy et al., 2015). Through our work in Luxembourg we have seen how open integrated programs, Science Workshop being one of many, provided ways for teachers to help students make connections between the languages skills they already possess and those they are learning in primary classrooms. Even if a school, school system, or national curricula dictate that a programs approach be monoglossic in nature, as it is in Luxembourg, we found traces of heteroglossic approaches to language use within science instruction. This type of instruction, promoted by scholars such as Flores and Schissel (2014), pushes back at monoglossic multilingual programs in ways that position students to use their multilingual competencies as resources for deeper and meaningful learning.

This work has important implications for science and primary school teacher preparation in that it is one example of a program that supports the implementation of an integrated science and language instructional approach that honors the language and cultural resources that students bring with them to the classroom. It additionally shows how teachers working within more traditionally oriented programs can create spaces that are heteroglossic in nature, and thus honor students' communicative strengths in ways that support both content and language learning, even if they are operating within monoglossic educational systems. And perhaps most importantly, it provides a way to listen to our students' questions and to let their voices lead the way.

The study now transitions from a presentation of work with teachers, to the analysis of interactions in a focal classroom co-taught by my research colleaguges, Christina Siry, Jana Haus, the classroom teacher, and myself. The two chapters (Chapter 3 and 4) presented next each draw upon interrelated, yet methodologically distinct analytic lenses, namely, interaction ritual chain analysis and multimodal interaction analysis.

CHAPTER 3

INTERACTION RITUALS AND IBSE INSTRUCTION: ANALYSIS OF STUDENT PARTICIPATION IN SMALL-GROUP INVESTIGATIONS IN A MULTILINGUAL CLASSROOM[9]

Abstract

Using a lens of interaction ritual theory, this study presents the case of a plurilingual student engaging in inquiry-based science through the language of instruction, a language he had not yet mastered. Micro-level interaction analysis illuminated how he interacted within four different small-group inquiry-based investigations over a six-month period. Two questions are answered, first, what is the nature of the interaction rituals that form in small-group interactions, and second, what does the nature of these interaction rituals reveal regarding students' participation in science practices and language use? Video analysis revealed that positive interaction rituals failed to form in the first few months of the focal student's interactions with peers in small-group investigations. It additionally revealed how this student's persistent use of participation strategies over time, within flexible student-directed investigations, afforded him opportunities to engage language resources, which resulted in successful interaction rituals with his classmates. This study demonstrates how the ritualised use of student-centred science pedagogies can create spaces for students to form successful interaction rituals that, in turn, support science engagement and language development.

Key words: interaction rituals, language learners, inquiry-based instruction, multilingual, student participation

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[9] Chapter 3 has been accepted through a blind peer-review process for presentation at the August 2017, European Science Education Research Association annual meeting to be held in Dublin, Ireland. Additionally, this chapter in currently in peer-review with the journal *Science Education.*

Introduction

Many classrooms throughout the world are experiencing shifts in the number of students who speak languages in addition to, or other than, the language of instruction (e.g. Camarota, 2007). In these classrooms, plurilingual[10] students are positioned to learn science through a language other than their home language, and often through a language they are still developing (Swanson, Bianchini, & Lee, 2014). This presents educators with the challenge of constructing learning opportunities that provide accessible instruction for a range of language learners, and presents students who are language-learners with the dual challenge of building science content understanding, while simultaneously supporting the development of language skills. There is a growing body of research that shows that when elementary language-learners engage in context-rich, student-driven forms of science instruction they increase both science understandings and language competencies (Lee, 2015; Lee, Quin, & Valdés, 2013). Student-driven science instructional approaches, such as inquiry-oriented science (NRC, 2000; NRC, 2012), can be particularly important for plurilingual students, who may not be proficient in the language of instruction, as they support dialogic engagement around science, which can also serve to mediate their language proficiencies. While there has been an increasing trend in the literature that considers students' language competencies in relation to their science experiences (i.e., Cuevas, Lee, Hart, & Deaktor, 2005; Llosa et al., 2016), There is a need for research that explores *how* students participate within the socially-embedded

10 In this study, the term *plurilingual* is used to describe students who possess diverse language repertoires that consist of various combinations of languages and communicative resources. The term *multilingual* is used to describe spaces of varied language use as recommended by the Council of Europe (2014). This builds from prior work in science education research that uses the terms *multilingual* students, *language-learners*, *English language learners* (ELLs), etc.

structures of inquiry-oriented activities in general, and how plurilingual students use linguistic resources during these interactions, in particular. Elucidating the nature of student participation in small-group science investigations is essential to support meaningful science learning, not only for language-learners, but also for all students, and is the overall objective of the research presented in this manuscript. As such, this study analyses the ways plurilingual students engage with each other and with language resources as they participate in the practices of science in the context of inquiry-oriented instructional units.

Inquiry-oriented Science and Plurilingual Students

More than two decades of education research have established the merits of inquiry-oriented science instructional approaches and their positive influence on student science learning (e.g. (Minner et al., 2010). In contrast to more fact-driven and teacher-centred forms of science education, which are typically dominated by teacher-centred lectures, inquiry-oriented instruction engages students in constructing science knowledge in deep and meaningful contexts (NRC, 2012; Worth et al., 2009). Through inquiry-oriented instruction, students are able to practice science in ways that promote dialogue and critical thinking. For students learning science through a second or third language, as was the case of the plurilingual participants in this study, student-driven hands-on science instruction can provide opportunities to engage in both the practices of science, and also in meaningful contextualised science conversations with peers (Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). Inquiry-oriented instructional approaches engage students in interacting with peers to formulate questions, design and conduct investigations, evaluate evidence in light of constructing new understandings (NRC, 2012). Students are positioned to dialogically interact with peers as they engage in science (Lee et al., 2005). Haneda and Wells

(2010) demonstrated that dialogic, inquiry-based science instruction supported plurilingual students in not only learning science content, but in also in the engagement of science process skills and in the development of scientific discourse.

While the advantages of such instructional methods have been the focus of a wide body of research, it is important to underscore that their support of learning is dependent on successful student interactions. Thus, for learning opportunities to occur, these socially embedded instructional approaches require student participation and linguistic engagement in communities of learning (e.g. Lave & Wegner, 1991). This assumes that students have access to the language resources and social tools that afford them meaningful participation. For students who have not yet mastered the language of instruction, this can construct barriers to participation in inquiry-oriented learning experiences. While the benefits of hands-on science for multilingual students are well documented, in this study we tease-apart an unexplored aspect of these instructional approaches. Thus, the research in this manuscript used a micro-sociological methodology to examine the rituals that form in small-group interactions in a multilingual classroom using inquiry-oriented instruction. Specifically, this study examines the rituals that form on micro-levels in small-group interactions as students participate in student-driven science investigations.

Classroom Rituals and Student Participation

In our national context in Luxembourg, science is commonly taught at the elementary school level using instructional approaches that are teacher-centred and teacher-driven (Michalik, 2010). These lessons subsume a set of "ritual elements" regarding participation, and ways of speaking and interacting that have been well documented in the field (e.g., Lemke, 1990). Teacher-centred instruction provides students with a limited range of ways to engage in science learning and a similarly limited set of ways to access language resources. Consider, for example, a teacher conducting a whole-class discussion about evaporation. Students can participate by choosing to raise their hand, or not. They can choose to face the teacher, or not. They can choose to speak in the class discussion in the ways sanctioned by the teacher, or not. In this lesson, participation in science learning is filtered through the context set by the teacher and prioritises the voices and ideas of students who speak in class and who learn well through teacher-guided discourse. Certainly, the predominance of such teacher-centred instruction is not unique to our context. However, education reform in international circles the past few decades has increasingly focused on creating opportunities for students to be more engaged in the learning process (e.g., Léna, 2009; NRC, 2012; Rocard et al., 2007; Rogoff, 2003), and has stressed the value of student-driven instructional approaches (NRC 2012; NGSS Lead States, 2013). These student-oriented approaches are relevant for our study in particular as such student-oriented approaches present a different set of possible ways students are able to interact with science content, with science processes, and with language.

A well-established body of research documents how student-centred science instruction positions students to interact with materials, each other, and language in discussion differently relative to teacher-centred instructional approaches (Haneda & Wells, 2010; Siry, 2013). For example, Roth, McGinn, Woszczyna, and Boutonne (1999), demonstrated in their study of a Grade 6-7 science class that not all activity structures afford students equal participation in science learning in the same ways. Their investigation of whole class lectures and small group student investigations revealed that several classroom features including the physical arrangements of the classroom, student access to learning artifacts and student interaction arrangements mediated students' discursive practices. Thus, how students interacted, what they talked about, and what they learned was directly related to the arrangement of the interactional setting. In a similar sense, student-oriented instructional approaches position students with regards to interaction and their access to resources in the classroom, in ways that are different from teacher-centred approaches. When these approaches are repeated over time, they become ritualised for both the teacher and the students. In this study, we explore what ritual interactions formed, and *how* they formed, when students participated in inquiry-oriented science explorations. In doing so, we aim to show how the rituals created mediated students' participation, science learning, and access to language resources.

Interaction Rituals in Science Classrooms

Several scholars in the field of science education research have examined classroom interactions using the lens of interaction rituals (Bellocchi, 2017; Elmesky, 2015; Milne & Otieno, 2007; Olitsky, 2007). Interaction Ritual Theory explains how groups that focus on a similar task can build a shared mood. This mood then can lead to synchrony that is almost imperceptible in group members' movements, speech, and embodied interactions. Interaction rituals (IR) occur in our everyday lives and can be as small and inconsequential as how we greet someone when walking down the street, or can be larger events in space and time, such as a political march or a sporting event. Collins built on the Interaction Ritual theories of Durkheim and Goffman (1967), to characterise the ingredients of interaction rituals (IRs) and elaborate how one ingredient can lead to a next, in a "chain" that passes positive emotion from one interaction to the next. In his book *Interaction Ritual Chains* (2004), Collins details a sociological theory of human interaction, and elucidates how an analysis of situations at the micro-level provides insight into the foundations of human interaction. He explains that humans seek out interactions in ways that generate positive emotions, and that if these positive emotion-generating interactions are repeated, the results can lead to entrainment and synchrony in a group in the short-term and solidarity over the long-term (Figure 3.1).

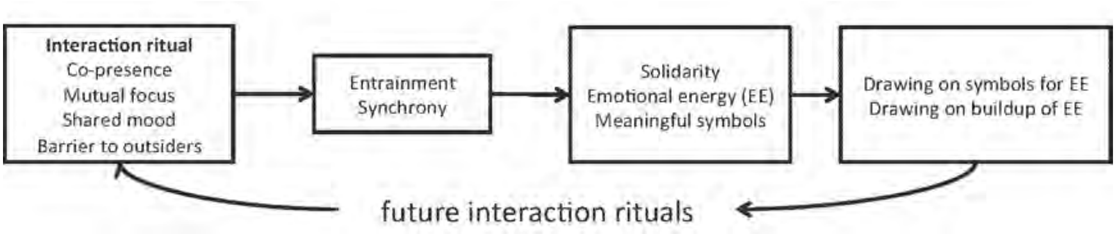


Figure 3.1. Collins' (2004) Interaction Ritual Chains (adapted from Summers-Effler, 2006)

We will elaborate this theory through the analysis presented, as we use Interaction Ritual Theory as a lens on the chains of interaction ritual that plurilingual elementary students engaged in during open-ended science investigations. Collins (2004) explains that there are interaction rituals that people engage in throughout social life which begin with the same basic ritual ingredients. These include being co-present in a group, mutually focusing on a project or idea, sharing mood, and a barrier to outsiders of the group (Figure 3.1). When the four ingredients are present, synchrony, and rhythmic activity can emerge in interaction on the level of microseconds and build among participants, which can subsequently lead to the generation of shared emotional energy in individuals and solidarity among the group. The emotional energy (EE) that is generated in the interaction ritual can be positively or negatively valenced. When it is positive, it can result in feelings of pride, contentment, and joy. When it is negative, it can result in feelings of dejection and demotivation. The EE that is generated can also become embedded in meaningful symbols. These symbols then can inspire further feelings associated with the group's interactions. Think of soccer fans, and the symbolism of a team jersey. These group-generated symbols (the team jersey) can be accessed at later points in time to tap once again into the emotional energy generated by the interaction ritual (the positive emotions experienced at a soccer game). As participants in interaction rituals draw on these symbols for generating further emotional energy, they seek future interaction rituals that lead to further shared emotional energy. This occurs in a chain, in that one successful interaction ritual (IR) leads to another, and thus Collins' theory examines the chains of interaction rituals that emerge in encounters.

The use of this theoretical framework has been used in science education to understand the nature of classroom contexts in several key studies. For example, Elmesky (2015) utilised video microanalysis to examine teacher-student interaction and student-student interactions in a high-school chemistry class. Elmesky (2015) additionally discussed analysed moments with the participating teacher and students. Discussions between participants about moments in the analysis revealed that first, the teacher made many unconscious moves that structured students' focus, and second, the students each responded differently (some positive, some negative) to the teacher's moves. This analysis highlighted specific teacher moves that could be repeated in future instruction to support successful engagement. Taken together, these two studies utilizing micro-sociological approaches to examining science classrooms (Elmesky, 2015; Olitsky, 2007), illustrate that IRT can be a fruitful approach to investigating interactions in ways that provide new insights into contexts of teaching and learning. In this study, we build on the work of these scholars to turn the focus to plurilingual, elementary-aged, students and examine interaction rituals as they form and evolve in small group investigations in an elementary classroom.

Similarly, Olitsky (2007) showed how an examination of interaction ritual chains between a teacher and her class in an eighth grade chemistry lesson revealed teaching practices that resulted in both successful and unsuccessful classroom interaction rituals among both teachers and students. Her analysis demonstrated how the teacher's attempts to include popular culture examples in instruction failed to generate positive student engagement. Contrary to the teacher's intent, a break in synchrony occurred with the whole class that is observed on the micro-level (tenths of a second), and student engagement declined. Olitsky's work demonstrates how microanalysis can reveal intricacies of classroom interactions that are often not conscious, yet that can have direct consequences on student participation and learning outcomes. Her research additionally demonstrates the power of interaction ritual analysis to provide insight into what works and what does not work in particular science learning contexts. Olitsky's (2005) study not only utilised IR Theory as a lens to examine science but additionally conceptualised students working together in a classroom as participation within a Community of Practice (Lave & Wegner, 1991). Participation within a Community of Practice means to engage collectively in work toward a common goal or on a common task. In the case of Olitsky's study, the students experienced positive interaction rituals, and a build-up in synchrony in movement and vocalizations as they worked together on balancing chemical equations at the blackboard. Teacher encouragement, and more importantly, positive student vocalizations helped the class work together as a community in learning how to balance equations. In classroom communities of practice, available cultural resources mediate the types of possible interactions. In another study, González-Howard and McNeill (2016) examined how English-learners engaged in scientific argumentation. By viewing the classes' interactions as a Community of Practice, their study revealed how aspects of student positioning and interaction both hindered and facilitated students' participation in scientific argumentation. They additionally found that when students worked in smaller groups, and had access to both native and second languages that student engagement was fostered. This study builds on these prior theorizations of science classrooms as communities of practice (CoP), as each small-group is conceptualised as a CoP, allow for a consideration of how its members are positioned in interaction as they complete inquiry-science investigations.

In the context of a larger study that investigated the use of an integrated inquiry-based science and language instructional program in a multilingual classroom context, the research presented in this manuscript approaches two research questions. First, what is the nature of the interaction rituals that form in small group encounters, and second, what does the nature of these interaction rituals reveal regarding students' participation in science practices and language use? Rooted in these questions, IR analysis is used to examine the case of one student who, despite a rich language repertoire, is not proficient in the language of instruction in this multilingual setting. The analysis of micro-level interactions and multi-level characterization of interaction rituals reveals this student's use of his language resources as he participates in several inquiry-based science investigations.

Context

An Integrated Inquiry-Oriented Science and Language Instructional Program

This study was a subset of a larger research project that examined the use of an integrated inquiry-based science (IBSE) science and language literacy pedagogical approach in multilingual elementary classrooms in Luxembourg. The instructional approach, titled Science Workshop, supported teachers in using integrated inquiry-based science and language approach to instruction. For a detailed description of the project see Wilmes (2016). In this subset of the project, three units of integrated science and language instruction utilizing inquiry-based science instructional approaches, were the focus of analysis. Each unit consisted of similar learning activities that engaged students in posing questions about science phenomena, and subsequently designing and conducting investigations to explore their questions. This framework encouraged a use of ritualised elements, such as periods of questioning in small-groups, and documenting science investigations in notebooks, that through repetition created spaces for students to have a voice in the learning process, and to additionally choose the language resources they drew upon. An overview of the three units involved in the analysis in this study is presented in Table 3.1.

	Water Unit	**Soil Unit**	**Living organisms: Worms Unit**
Science Content Focus	Condensation and evaporation	Composition and physical properties of soil	Characteristics of organisms
Science Process Focus	Generating questions from observations Designing and conducting investigations Communicating results		
Duration	5 classroom sessions	3 classroom sessions 1 outdoor session	1 University workshop session

Table 3.1. Overview of three inquiry-based science units

The Plurilingual Student Participants

This study was conducted at City Primary, a mid-size elementary school, serving approximately 350 children in Luxembourg City, Luxembourg. The analysis we present was derived from the use of the integrated inquiry-based science and language program, Science Workshop, in one fourth-grade class (10-11-year-old children), comprised of 15 ethnically, social-economically, and linguistically diverse students. Luxembourg is a multilingual country, and there are three official languages, the national language of Luxembourgish, and two other official languages, German and French. These three languages are reflected in the school policy, which is trilingual and expects students to not only be proficient in all three languages before completing elementary school, but additional learn science through the use of German starting from age six (Ministére de l'Éducation nationale et de la Formation professionnelle, 2011). All 15 students in this classroom were plurilingual in a myriad of linguistic combinations and used Luxembourgish in their daily interactions with their teacher. Profiles of the linguistic repertoires for the six students detailed in this study are shown in Table 3.2.

Name	**Luxembourgish**	**German**	**French**	**Bosnian**	**Montenegrin**	**Russian**
Teo (focal student)	X		X			
Mila		X	X			
Natalie					X	
Luc		X	X			
Neal	X	X		X		
Wayne	X					X
Role in Luxembourgish elementary classrooms	Language of instruction	From age 6 Literacy and content (science, geography)	From age 7 Literacy	-----	-----	-----

Table 3.2. Student language profiles and the languages of instruction. X denotes a language spoken at home. Black boxes denote languages with an official place in the trilingual elementary school curriculum.

This complex linguistic landscape is a crucial component of this study as the majority of students in this class were learning science not in their home language, but rather through a second, or third language and all students were working in these investigations and classroom routines in at least two different languages. Table 3.2 details the language profiles of the six students presented in this study.

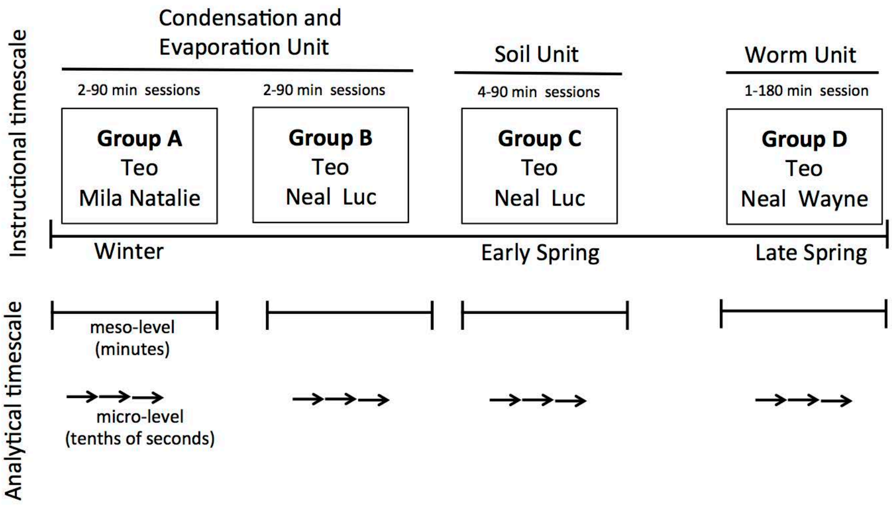


Figure 3.2. Project timeline showing four student groups across three inquiry-based units

Important to note is that there were three researchers co-teaching the unit with the classroom teacher, thus there were four adults present in the classroom, which provided multiple participant observers perspectives. Of the four teacher / researchers, all of us spoke German with the students (the official language of instruction for science) and the classroom teacher additionally spoke Luxembourgish with the students intermittently, particularly when she was checking their understanding of what was discussed in German.

This study examines IRs and IR chains for four student groups across a six-month period, comprised of different combinations of students (Figure 2). Nested within the analysis of these groups we present a case study of Teo[11]. Teo worked within each of four small- groups over the study. He was chosen as a critical case (Patton, 2015) for three reasons. First, initial video analysis revealed that at the start of the study Teo did not willingly participate in whole-class discussions in German. Second, during less structured classroom moments he often spoke to the research video cameras in French. Third, during student interviews Teo explained that he speaks French most often in out-of-school contexts including at home. This is significant because in Luxembourg elementary classrooms, French is primarily

11 All participants have been assigned pseudonyms to maintain anonymity.

relegated to French literacy lessons. Thus, students are typically not encouraged to use French, or any of the other additional languages other than German or Luxembourgish, while learning science.

Methods

This qualitative study employed an ethnographic approach to investigate interactions as they unfolded during elementary science instruction across both micro- and meso-levels of interaction in a multilingual classroom. Our work is situated within sociocultural views of science and engagement in classrooms (Tobin, 2012) and language resource engagement (Creese, 2008). As such, our research views science as a contextualised practice that happens in interaction as students mobilise resources collectively and employs qualitative methods that examine student participation in a classroom in ways that reveal the socially-situated ways students interact with each other, and the culturally embedded tools they access during science investigations.

Data Sources

Over the course of six months, three science units with unique content objectives (Figure 1) were documented through the collection of multiple sources of data, as detailed below. Iterative cycles of video analysis on both meso-levels (on the scale of minutes) and micro-levels (tenths of seconds), allowed for the characterization of synchrony for each student group on both levels (Figure 3.2).

1. Whole class videos. Two cameras captured all classroom activities for the duration of all inquiry-based units.
2. Tabletop video cameras. Small video cameras placed on each student-group table captured close-up videos of small-group work.

3. Learning artifacts. All artifacts produced by individual students, small-groups, and the class were collected and archived. These include student science notebooks, class posters, and student question cards.
4. Student interviews. Semi-structured student interviews were conducted with the students at the culmination of the Water unit. These interviews were key in revealing students linguistic repertoires (Busch, 2012) and their views of interactions occurring during the inquiry-based investigations.

Student focus-group interviews were conducted following the first unit in German and Luxembourgish. The semi-structured interviews explored participants' views of their language repertories including the languages they speak at home and their preference for language use in out-of-school contexts. Additionally, the interviews provided an additional layer of students' personal reflections on their experiences (Elmesky, 2015) of interactions with peers while working on science investigations in small groups.

Situations as the Unit of Analysis

This research is rooted in frameworks that recognise the inseparable relationship between the individual and the collective (Lave & Wenger, 1991; Olitsky & Milne, 2012). While Teo is presented in this manuscript as a critical case, we stress that this study analyses his interactions with group members embedded in small-groups working within a classroom context. Thus, Teo's participation in the classroom is related to, and mediated by, the structures within the encounters, which includes the materials, the objectives of the investigation, and his interaction with his peers (Collins, 2004). What is revealed through analysis of these situational facets regarding Teo's participation, is a manifestation of his interaction with the small group, and vice versa. Therefore, we analyse the interactions within these small-group situations, and use this small-group interactional analysis as entry points for revealing Teo's use of language resources and engagement with science practices within four different student groups over the course of the study.

Data Analysis

A multi-level analytic approach afforded views of student interactions on the micro-level (tenths of seconds), which were nested in the meso-level organization (minutes to hours) (Figure 3.2), of learning activities as they unfolded across three inquiry-based science units. The first level of analysis involved watching all classroom videos for all units in real time. A log was created for each science unit that indicated the learning structures (whole class activities, small group activities), participants, and languages undertaken in each activity. Student interviews were analysed during this first level and provided evidence used to construct linguistic repertoire profiles for each student (Busch, 2012). A process of purposeful sampling (Patton, 2015) was used to identify focal student groups who employed a language that was not a language of instruction in interactions or in written productions.

A second layer of video analysis examined group interactions on the micro-level (frame-by-frame at one tenth of one second) for focal student groups. Analysis involved video analysis of small-group work for focal groups in real time, and then noting frame-by-frame the ingredients of interaction rituals including, bodily co-presence, mutual focus, barriers to outsiders, and synchrony (Table 3.3).

Interaction Ritual Ingredients (Collins, 2004)	Characterization at the micro-level
Co-presence	• Position of group members relative to focal interaction • Position relative to multiple participants
Mutual focus	• One focus, multiple foci, no focus • Duration of mutual focus • Gaze, body position relative to mutual focus
Barrier to outsiders	• Do others visit the group? How often? Whom? • Do members of the group leave? How often? For how long? • Do members set up barriers through linguistic means, physical means, emotional means?
Shared mood	• Description of mood (positive, focused, angry, agitated, playful) • Do all members share the mood? • How long does it last?

Table 3.3. Characterizing IR ingredients in small-group interactions

Based on the initial characterization of IR ingredients in each group, each group was next characterised as to first, the forms of synchrony that developed, second, the role of Teo as an assistant or director during science investigations (Siry, Wilmes, & Haus, 2016), and his use of language resources within the group. Taken together, multi-layered characterizations of participation and interaction at both meso- and micro- levels (Elmesky, 2015) were compiled for each of the four groups. All spoken data were transcribed in the language spoken (German, Luxembourgish, or French) for analysis purposes. Focal moments were subsequently translated into English for purposes of manuscript publication.

Multiple researchers who speak French, German, and/or Luxembourgish used standardised procedures to ensure the accuracy of all translations. Data analysis was shared with research colleagues at multiple points during the analytical process to discuss claims that crystalised from analysis.

Small-group Science Interaction Rituals

The main claim supported by this study is that ritualised science and language instructional approaches positioned Teo to participate in successful interaction rituals over time. Through the repetition of successful positive IRs over time that resulted in higher degrees of group synchrony, he was able to participate in small-groups in ways that allowed him draw upon his linguistic resources and, in doing so, participate more fully in inquiry-based science investigations in a language he had not yet mastered. Multi-level analysis, as described in the preceding sections resulted in the characterization of synchrony and participation (Table 3.4).

In the sections that follow, we detail evidence of the forms of synchrony that developed in each of the four small groups over a six-month period (Figure 3.2) to support the characterizations for each group. An overall characterization of synchrony is presented first for each group. This is followed by analytic discussion that focuses on Teo's participation in the science investigation and language use within each of the four groups (Figure 3.2). While we find it important to call specific focus to these dimensions of interaction as they support the claims that arose from analysis, our theoretical grounding in sociocultural views of science learning (Lemke, 1990) recognise the interrelatedness of these meaning making resources in science classrooms.

Group A: Asynchrony

In Group A, Teo worked with two students Mila and Natalie (Table 3.2), for forty minutes to design and conduct a science investigation exploring their questions about condensation and evaporation (Table 3.1). Video analysis of the investigation period showed the three group members mutually focused on the materials, as revealed through their gazes toward each other and toward the materials (Figure 3.3).

Figure 3.3. Teo works with Mila and Natalie on a science investigation.

Even though the body positions and gazes of all three group members were oriented toward the investigation materials, Teo was often positioned farther away from the materials and from the other group members. For the majority of the investigation Teo frequently looked over Mila and Natalie's shoulders (Figure 3.4a, b). As a result, he did not have a direct role in material manipulation during the investigation. In Group A, Teo's access to the scientific materials was blocked, thus undermining the generation of positive successful rituals.

Figure 3.4. Teo is consistently positioned farther from the investigation
Than Mila and Natalie

Table 3.4. Synchrony and language use in four student groups across three science units

			Evaporation and Condensation Unit		Soil Unit	Worms Unit
Group			A	B	C	D
Students in group			Teo, Mila, Natalie	Teo, Luc, Neal	Teo, Luc, Neal	Teo, Neal, Wayne
Group synchrony			Asynchronous	Off set	Synchronous	Synchronous
Teo's role in investigation			Recorder	Assistant	Director and assistant	Director and assistant
Language use	**Teo's German usage**	**with teachers**	Silent engagement	Silent engagement	Silent engagement	Initiates verbal interaction
	Teo's German Usage	**with peers**	Structured by activities	Structured by activities	Structured by activities	Structured by activities

During the forty-minute investigation period, Teo travelled to other groups four different times. Teo's repeated travelling to other groups is an indication of looser co-presence among the three members of Group A. Collins' (2004) theorizing of interaction rituals explains that humans seek out positive emotional energy (EE) and interactions that will lead to the production of more positive EE. In this light, Teo's leaving is interpreted as an embodiment of his search for a group with which he could form more positive IRs, and subsequently participate in a more positive emotional climate.

As the investigation continued, Natalie took on a lead role and the group followed her plan. She turned at one point toward Teo and commanded, "You must help me!" as he stood looking toward her with his hands down by his sides. Participatory science investigations, such as those that were used in this classroom, structure group interactions in ways that allow members to negotiate group roles. This negotiation can provide all members with equal access and result in equal roles when conducting science investigations, or unequal access with some delegated to assistant-type roles with less access to decision-making and material engagement (Siry et al., 2016). The latter was the case for Teo in Group A. Teo followed the directives set out by the two other group members. This was seen again when Natalie told him, "Teo! Give me that!" while she indicated that he should hand her a pipette. In response, Teo looked away, and then walked to another group. His movement is a physical manifestation of the non-cohesiveness of the group, and the failure to generate positive IRs through micro-level interactions. Video analysis revealed that on the overall, there were low levels of positive emotional energy and low levels of entrainment that formed among Mila, Natalie, and Teo. As such, Teo's encounters in Group A are characterised as *asynchronous* (Table 3.4). Next, we continue with the analysis of Group A to elaborate the IRs that were evident in this group regarding science practices and language use.

Science interaction rituals in Group A. Ten minutes into the investigation with Group A, Teo began to repeat Natalie's motions. She first raised her finger. Teo repeated this motion (Figure 3.5a). Then she lowered her arm, with her elbow bent. Teo mirrored this movement also (Figure 3.5b).

Figure 3.5. Teo copies Natalie's motions

This was interpreted as Teo's attempt to break through the low level of positive collective emotional energy, and to attempt to change his position within the group. Research conducted by Sullivan and Wilson (2013) investigating the role of playfulness in small group interactions during science lessons concluded that mimicking movements, such as Teo's, can be seen as a student's attempt to affect their position in a group, and to strengthen bonds toward the goal of increased group coordination. What followed Teo's playful repetition of movement was central to the interpretation of this interaction and understanding his attempt. Natalie and Mila made frustrated faces and gestures toward Teo and maintained their bodies positioned away from him, but toward the investigation, and they carried on working without engaging with Teo. In summary, his bids to participate did not result in increased positive interactions between him and Mila and Natalie.

Language interaction rituals in Group A. Analysis of Teo's language interaction rituals in Group A identified several key moments during the forty-minute investigation period. During several teacher-initiated interactions, when the teacher approached the group to monitor their progress, Teo interacted with the same repeated embodied action. The teacher approached the group and Teo remained engaged through gaze and body orientation, but positioned himself peripherally. As previously elaborated, one of the instructional goals of this Science Workshop unit was for students to communicate about their investigations in both written and spoken German. Towards this goal, the teacher conversed in German with the group. Natalie and Mila replied in German with detailed explanations about what was occurring. Teo maintained his gaze toward the teacher and his group mates from his non-central position. He nodded at several points in the conversation, but did not participate verbally. Research on the silent participation of students immersed in new language environments reveals that their participation, characterised as legitimate peripheral participation (Lave & Wegner, 1991), is revealed through their gaze at a common focal point, and their body position oriented toward the focus of the conversation, but without verbal participation even when they are directly addressed (Bligh, 2014). In the moments shown, Teo repeatedly engages in silent participation in German interactions at several points during his work with Group A.

Video analysis revealed that Teo initiated interactions in German *only* when activities instructed that German be used, and only in informal contexts, when a teacher was not involved in the interaction. In the next moment presented (Excerpt 3.1), the teacher instructed the class to *Describe what happened with your investigation*[1]. *Write what happened, or draw what happened in your science notebook*. After receiving these instructions, Teo turns to his group and mirrored the teacher's phrase in German, *Natalie, I am writing what happened* (Excerpt 3.1, line 01) and the following interaction ensues:

Figure 3.6. Teo sits to the side of Group A watching as Natalie and Mila work (a). After attempting to converse with them in German, he turns to the side (b) and writes a journal entry describing what the group completed for their investigation. (c).

Excerpt 3.1. Teo tries to get Natalie's attention[12]

Line	Speaker	Talk	Action
01	Teo	I am writing what happened.	Looking toward Mila and Natalie (Fig.6a)
02	Natalie	O::kay	Facing materials, hands on a metal plate
03	Teo	What happened here?	Leaning in toward materials and
04		Natalie, what happened?	pointing toward materials with a pipette
05	Natalie	So….Hhhggghh, FINALLY!	Rearranges the materials on the table in front of her
06	Mila	And what are we doing now Natalie?	Picks up tin pan while looking at Natalie
07	Natalie	Aaag….. Now we need tape. Get two big pieces.	
08			Teo turns away from Mila and Natalie and writes in his science journal at the opposite end of the table. (Figs. 6b,c)

12 Key to transcriptions
BOLD for emphasis
: stretched out sound
|| with indentation brackets overlapping talk
... pause
xxx unintelligible speech
(.20) timed pause

Natalie acknowledged his statement with *okay* (line 02), and continued to manipulate the investigation materials. Teo asks Natalie, in German as he points to the set up materials with a pipette he has in his hand, *What happened here*? (Excerpt 3.1, line 03, Figure 3.6b). In this moment, he repeated the German phrase that structures the activity (*What happened),* three times. Teo used this strategy of repetition often. He draws upon language structures provided by instructional activities, in this case the question, to frame the interaction he initiates talk in the language of instruction (German). Teo's attempt to engage Mila and Natalie in German to describe the investigation (by repeating "What happened?" in lines 03 and 04), failed and Natalie instead replies directly to Mila (line 07). Nevertheless, Teo turns his body to the side of the table away from his group mates (Figure 3.6c) and writes a detailed entry in his science journal. The level of detail in his journal entry (Figure 3.6c) demonstrates Teo's awareness of the progress of the investigation, regardless of the asynchrony and low levels of positive emotion he shared with Mila and Natalie. Teo acted in the role of recorder as he successful documented their investigation, Analysis of student interviews supported conclusions we drew from video analysis in that both Mila and Natalie described being frustrated with Teo and explained that they felt he did not contribute to the investigations. In sum, Teo's interaction rituals in Group A were asynchronous, during which he participated primarily as a recorder for investigations.

Group B: Offset Synchrony

In Group B Teo worked within the same unit on condensation and evaporation, but with a new investigation plan and with two different students, Luc and Neal (Figure 3.2). At home, Luc speaks French and German, and Neal speaks Luxembourgish, German, and Bosnian (Table 3.2). This is important to analysis, as

Teo shared French as a home language with Luc and was often heard speaking Luxembourgish or French with Luc, but only Luxembourgish with Neal. The differential use of languages among the members of this group is relevant to the analysis we present in that sharing French as a home language allowed Teo to participate within this group.

Group B was engaged and focused over the forty-minute period as was apparent in their mutual focus in interaction to complete their investigation. They moved fast to collect materials, and had quick interactions with little elaboration as they moved materials into place, discussed next steps, and executed their plan. They, in comparison to Group A, exhibited a higher degree of bodily co-presence, as indicated by a longer duration of time spent together in a circle with a tighter radius focusing on the same investigation. There was a build-up of positive emotional energy but at a less intense level relative to what we will show later in this manuscript that developed in Group C. Micro-level video analysis of Group B's interactions revealed the build-up of synchrony that was offset or delayed by an interval of tenths of seconds to minutes. This form of delayed synchrony we term *offset synchrony* (Table 3.4). Offset synchrony differs from synchrony that builds during more positive IRs in that the ingredients for IRs are present but the interplay between group members' interactions are offset in time. Key moments that illustrate this claim of offset synchrony are presented in the sections that follow.

Science interaction rituals in Group B. Group B started by discussing their plan to investigate condensation and evaporation. Neal presented an idea and was seen discussing the details of the plan with his body and gaze turned toward Luc. Teo watched their interaction without participating verbally (Figure 3.7a, b). Next, as the two group mates documented the details of the plan in their science journals, Teo asked Neal in Luxembourgish, *What is that?* as he pointed to the plan in Neal's science journal (Figure 3.7c). Neal explained to Teo each of the elements shown in his notebook, and then Teo declared, *Okay, I will do that too.* Teo then constructed the same entry in his journal, while looking over at Neal's journal (Figure 3.7d).

In this moment, Teo successfully employed a mirroring strategy, which Bligh (2014) refers to as not 'just' copying, to participate in the planning phase of the condensation and evaporation investigation. This was a strategic move on Teo's part to access the plan, and thus resources available to him through his group mates. Teo remained engaged with Luc and Neal as revealed through his body positioning and gaze and recorded the same plan as them, but offset by several minutes.

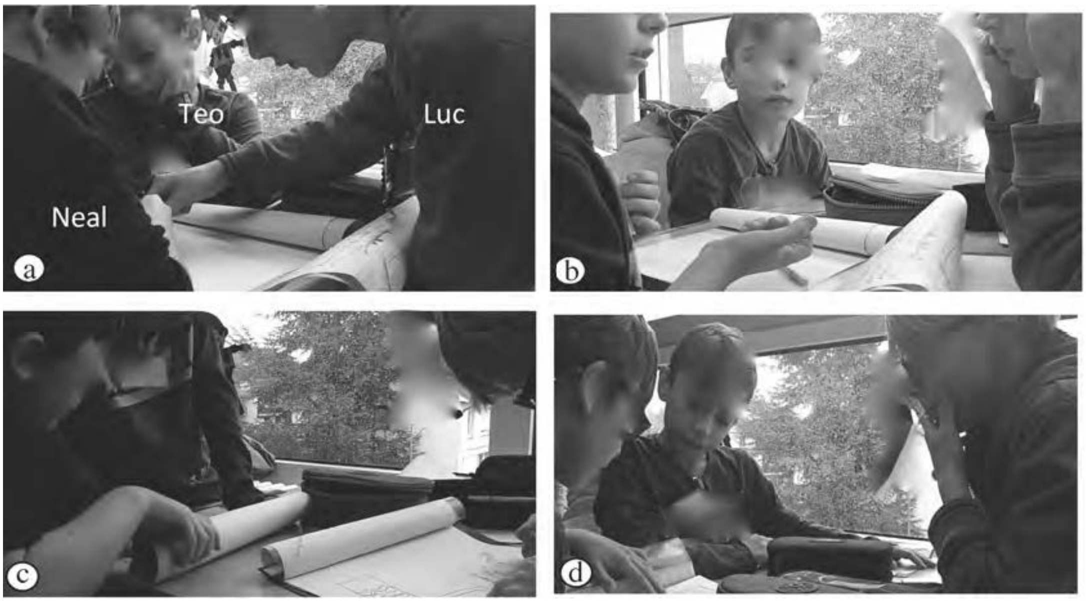


Figure 3.7. Teo works with Group B. He watches an interaction between Neal and Luc as they discuss the group's investigation plan (a, b). He then asks Neal what Neal has recorded in his notebook (c), and states he will record the same plan in his journal as well (d).

Offset synchrony builds in Group B again some minutes later as the group conducted their investigation. Teo was positioned one-step back relative to the table and the materials (Figure 3.8a, b). He was engaged, as revealed in his gaze and body orientation angled toward the materials, and his enthusiasm while participating, but he was offset in position from Luc and Neal and the investigation materials. As a result, Teo rarely directly manipulated the materials. He often retrieved them from the supply table but then handed them to Luc and Neal. As such, he acted as an assistant during the investigation. In one specific moment, Luc and Neal both walked away from the table. Teo moved quickly and directly toward the table. He picked up the materials and executed the exact moves with a magnifying glass and metal pan that Neal and Luc had conducted just moments prior. Teo used absence as an opportunity to move from his peripheral position to a more central position, and repeated their actions.

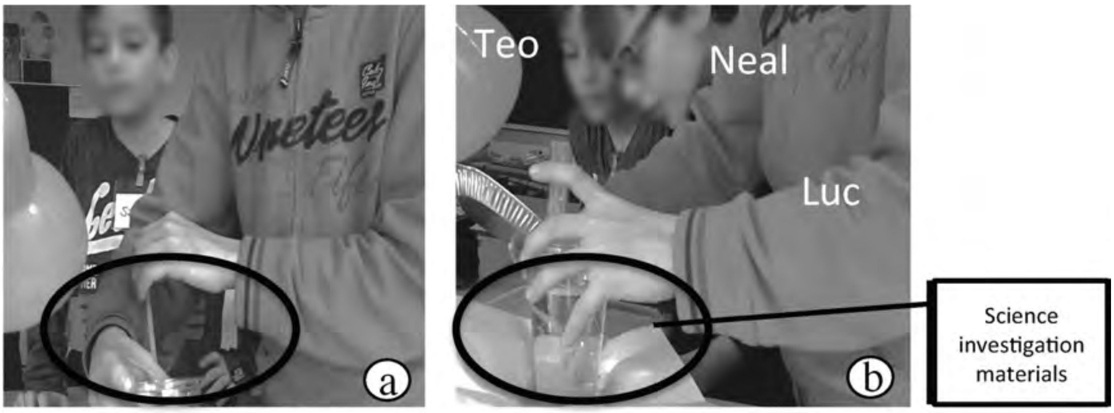


Figure 3.8. Teo watches as Neal and Luc perform the group's investigation

Language interaction rituals in Group B. At several points during Group B's investigation, the teacher approached to ask about their progress and spoke with the group in German. During these teacher-initiated interactions, Teo participated by maintaining his gaze and positioning his body toward the teacher, but he did not speak in German. In fact, he was not heard speaking at all. Additionally, Teo moved farther back from the teacher during the teacher-initiated interactions in German (Figures 3.9a, b). This backwards movement was interpreted as Teo's effort to distance himself from the German interaction, and to maintain his silent participant status (Bligh, 2014). This form of participation ritual, which we draw from theories of participation and sociolinguistics (Lave & Wegner, 1991; Bligh, 2014), encompasses a set of ways of interacting that Teo engages in and that mediate his participation. Analysis presented in subsequent sections will show that he repeated these participation rituals (in Group A and Group C), and through their use, he remained mutually focused with the group and the teacher, and was positioned farther from the interactions occurring in German. These moves are interpreted as successful participation rituals in that Teo engaged with the group, but did not need to speak German. Thus, he silently participated, and Group B continued to investigate in a cohesive manner.

Figure 3.9. The teacher approached the group and began discussing their plan. Teo moves from his initial position (a) back to the windowsill (b) increasing his distance from the teacher and her interaction with Neal and Luc in German.

Teo did not initiate interactions in German in Group B unless prompted to do so by an activity, or through the support of a peer. This occurred when teachers asked the small groups to write investigation questions on index cards. The index cards served as an informal record of students' questions. In a six-minute encounter, Teo, along with Luc and Neal, discussed which question they would record. During this encounter, Neal playfully attempted to engage Teo and Luc in "making a movie" for the research camera. Teo and Luc ignored Neal's bids, and continued instead to discuss their ideas in both French and Luxembourgish (Figure 10a). Teo, in an emphatic moment, stood up, leaned closer to Luc and declared in French, *That is a question, in fact!* (Figure 3.10b) meaning that their idea was a good investigation question that should be recorded on the index card. Teo's use of French in this moment, coupled with his body movement in standing up over the table and leaning toward Luc is seen as a move to interact more strongly with Luc, and an attempt to override the playfulness in the moment of Neal. By interacting in French, Teo was able to participate directly with Luc, and place a barrier between the two of them and Neal. This was supported by what Neal described in his interview, that he does not feel comfortable speaking French, and that he would not choose to do so with his classmates. Thus, Teo utilises these linguistic resources and strategies to form a stronger interaction between himself and Neal.

Luc follows Teo's move by saying to Teo in German, *Why does (the rain) only drip on Ronny?* (Ronny was a character in the science problem the students were investigating). Teo immediately sat down, and began writing the question in German on the index card (Figure 3.10c). Then repeated back to Luc, *Why did it drip….why did it drip…* he says, sitting up and looking directly at Luc, and again repeats with more force DRIPPED. In this moment, Teo's gaze toward Luc, his emphasis in tone and force when he says DRIPPED and the sequence of the interaction (writing-speaking-looking down, then repeating with force-looking at Luc) was interpreted as Teo checking that he had written the correct question in German. Teo follows this by looking back down at the index card, and while writing in a quieter and more drawn out voice, saying, *drip:::ped …on Ronny*. In this moment, Luc assisted Teo in writing the question in German. Positive emotion built up through this successful interaction, as was visible in the smiles Luc and Teo share immediately following their interaction (Figure 3.10d).

Figure 3.10. Teo listens as Luc and Neal speak (a). He interjects in French (b), then writes their question on an index card (c), and when finished shares a smile with Luc and Neal (d).

Summers-Effler (2006) in her ethnography of small group interaction rituals, explains that, “The emotional consequences of (group) successes mark symbols in their interactional environment with emotional significance” (p.148). In Group B, Teo and Luc recorded a question they were proud of on the index card. In turn, the question became imbued with positive emotional significance. This question became a symbol of the group’s positive interaction rituals, and charges Teo with positive emotion. This positive IR became significant in what it mediates in interaction one hour later, as we next elaborate.

After working on their investigation plan, and then going outside for recess, the teachers convened a whole-class discussion and asked students to share their questions. Teo raised his hand to participate in the discussion before the teacher finished giving instructions for the discussion. The teacher first called on a different student. Teo remained with this hand raised, holding the index card while the other student spoke to the class (Figure 3.11a). Teo made anxious sounds and appeared eager to share as his hand was raised and waving during the other student’s turn at speaking (Figure 3.11b). The teacher then called on Teo and he spoke in German in front of the class (Figure 3.11c). A transcript of what Teo said in this second excerpt highlighted herein follows.

Figure 3.11. Teo waits with his hand raised as the first student called upon speaks (a), and then enthusiastically tries to get called upon (b), and when called upon, reads the questions off the index card in German (c).

Excerpt 3.2. Teo reads his group's question to the class

Line	Speaker	Talk	Action
01	Teo	Why did it dri:::p only on Ronny?	Looking down and reading from the index card
02	Teacher	Why what?	
03	Teo	Why did it drip	
04		DRIPed	
05		driPED	
06		only	
07		only on Ronny?	

As Teo spoke, he was uncertain about how to pronounce the verb "drip" (*tropfen* in German) and read it from the index card (Excerpt 3.2, line 01). He attempted multiple times to say the words while emphasizing different syllables (lines 04 and 05). His prior successful IRs with Luc and Neal provided a build-up of positive energy that he was able to transfer to this later occurring whole-class discussion. Teo enthusiastically initiated speaking in front of the class in German, with the written question on the index card as support. The index card served as a symbol from the past successful IRs. The card and the positive emotion that went into its production was carried forward, and served to support Teo's initiative in speaking to the class in German. Thus, through the strategies he embodied and the resources available to him, a level of synchrony developed that, although slightly asynchronous and "out of step" in time, served to mediate Teo's involvement in Group B.

Group C: Synchrony

In Group C, Teo worked again with Luc and Neal, but on a different unit of study during which they explored the nature and properties of various local soil samples using soil tests and microscopes. For the duration of this unit, all three members of Group C embodied higher levels of synchrony than were observed in Groups A or B. In summary, Group C's interactions were characterised as synchronous, meaning displaying movements, utterances, and gazes that occurred in tandem at rates that were parallel (Table 3.4).

Science interaction rituals in Group C. Many positive IRs occurred which resulted in both verbal and positional synchrony in Group C. In these moments, (Figure 3.12) the group was mutually focused on exploring the color of dry dirt, versus wet dirt, versus dirt mixed with ink. The co-presence of Teo, Luc, and Neal at the investigation table was visible in their close proximity to the science materials, and to each other. They passed materials back and forth, while mutually focusing on the investigation materials in front of them. Their facial gestures often mirrored one another, and were passed from one student to another.

Figure 3.12. Moments of verbal and embodied synchrony in Group C.

This happened as one student made a facial expression which was held by the first student, and then passed around to the other two students until the entire group shared the same facial expression (Figure 3.12a). One particularly notable episode of a high level of synchrony occurred while the group used a microscope to examine characteristics of the soil grains. The three students stood with overlapped bodies (Figure 3.12b). Their heads moved simultaneously toward the microscope, their hands worked in the same tempo and at the same time to move the focus knobs, and all three students attempted to look through the ocular lens simultaneously. Through these investigations, Teo's was positioned as both a director of investigations and as an assistant. This is in direct contrast to his work with these same students' months early in Group B. In Group C, he spent equal amounts of time directing the group in executing his ideas, and assisting in implementing his classmates' ideas. Over the 4 sessions of this Soil unit, many similar instances of synchrony, and expressions of positive emotion, were revealed through video analysis, indicating a series of successful IR chains.

Language interaction rituals in Group C. For the majority of interactions in Group C Teo, Luc and Neal spoke Luxembourgish as they interacted. Teo did not initiate interactions in spoken German with Luc or Neal, nor with his teachers. When the teachers approached the group and spoke in German, Teo again positioned himself more peripherally. This allowed him to silently participate in the interaction without needing to speak German. As with Groups A and B, Teo spoke in German only when an activity required that he use German. In one moment, students were asked to record observations of the soil sample in their science notebooks using the sentence starter, "*I see" (in German)*. Teo used this sentence starter to speak with this group and to himself before writing in German in his notebook. Teo said to Neal, while laying his head briefly on Neal's shoulder, *I see...uh* ((looking at the container of soil))…*an ant*. Teo next looked down at his journal, then over toward Neal, then back to his journal and then wrote the phrase "I see an ant" in German in his science journal. Next, he looked up again at the jar of soil and repeated in German, *I see*…(leaning over toward Neal, looking down at his journal, then back at Student 5))..*uh*..(looking back into the jar of soil)…*small stones*. Luc echoed right after, *I see small stones (in German)*, and Teo repeated after him, in tandem with Neal, *small stones* almost simultaneously. This identical speech from both students that occurred simultaneously illustrates how the activity structured both Teo's use of the phrase, *I see*, in German and how the three students repeated each other's phrases with a higher degree of synchrony than was observed in Groups A and B. In summary, in Group C, the successful IR chains fed into one another, and further mediated Teo's participation in working with Group C.

Group D: Higher Levels of Synchrony

This fourth group (Table 3.1 & Figure 3.2) was run as a science workshop staged at the University with which we are affiliated. The investigation period was one, longer session (3 hours), but the same ritualised science engagement and ritualised investigation strategies as were used as in prior units. For this third unit, Teo worked in a triad with Neal and Wayne (Table 3.2).

Science interaction rituals in Group D. Video analysis of Group D's science practices revealed multiple elements of successful positive IR chains. First, the three members of the group were co-present and mutually focused around the investigation materials, as revealed through their body positions and gaze (Figure 3.13a, b). Mutual focus was maintained through synchronous interactions. A high level of co-presence and mutual focus was particularly apparent during one moment when the group moved from one workshop room to another. The three members of the group were observed moving from one location in the workshop room to another. Through this movement, they retained cohesive interactions, as revealed through alternating lines of talk. This type of unbroken movement was characteristic of the high level of mutual focus and synchrony that video analysis revealed developed in Group D.

Figure 3.13. Group D mutually focuses on observing their sample of worms and insects

Group D shared multiple moments of high positive energy with very enthusiastic exchanges about the worms they were investigating. As they searched for worms and insects in their sample they could be heard exclaiming in Luxembourgish, *I found one*! and a few seconds later, *I found another one!* They then returned to discussing their observations in more emotionally neutral tones. A second positively emotionally charged moment is presented in Excerpt 3. Teo and Neal were both observing a container of worms as Wayne filmed their work using a hand-held camera. Teo found a worm cocoon and proclaimed, *What a big cocoon!* At the same time Neal simultaneously proclaimed, *xxx another worm …But BIGger*. This excited overlap in speech was accompanied by rising intonations and occurred three times (Excerpt 3.3, lines 02, 04, and 09) in an interaction lasting less than a minute. This form of overlapping speech or latched speech provides evidence of group synchrony (Collins, 2004; Olitsky & Milne, 2012).

Excerpt 3.3. An emotionally charged, latched speech pattern in Group D interaction

Line	Speaker	Vocalization
01	Teo	What a big egg!
02	Neal	ǀxxx another worm…but BIGerǀ
03	Teo	Look there's a cocoon
04	Nate	ǀxxxǀ
05	Teo	Look a MEGA big one!
06		Xxx the cocoon
07		There is a REALLY big one!
08		Oh yeah
09	Nate	ǀI found a really big oneǀ
10	Wayne	ǀxxxxǀ

Language interaction rituals in Group D. Video analysis revealed a change in Teo's German usage while working in Group D. In one key moment, Teo picked up a worm cocoon on a spoon, and made three verbal bids to Wayne, in Luxembourgish to, *come*. Teo wanted Wayne to follow him with the camera back into the adjoining workshop room but Wayne did not respond to Teo's request. Teo then repeated *come*, three more times. As he repeated his request, Teo walked away from the group. Wayne then initially recorded Teo walking away, Next, Teo returned to Wayne and Neal at the table. He made another request for Wayne to follow him into the next room. Wayne eventually followed Teo's lead, and filmed Teo walking into the next room with the worm cocoon held on a spoon. A second camera angle of the episode revealed that Teo walked into the adjoining room, to the three teachers who were standing in a circle talking (Figure 3.14a, b).

Figure 3.14. Teo walks up to the teachers (a, b) and initiates a conversation in German (c), which results in a group conversation about the cocoon he found.

Once he was next to the teachers, Teo begin an unscripted conversation in German, explaining what he found. Teo and the teacher discussed, through several turns of conversation in German and a mixture of German and Luxembourgish, the worm cocoon Teo found (Figure 3.14 c, d). The episode closes with the teacher and Teo engaging in a mutual positive exchange as revealed in their gazes at and body positions oriented toward each other. Teo's initiative can be explained as the outcome of the build-up of positive emotional energy from Teo's participation in successive positive IR chains. When viewed through the lens of IR theory, this moment reveals that Teo had experienced past positive experiences with interactions in German, and with science investigations, as was presented for Groups B, and C. This resulted in a build-up of positive emotions for Teo and led to an increase in Teo's confidence, as exhibited in his initiation of interactions with the teachers. Successful IRs can be revealed as feelings of empowerment and confidence in ways that compel people toward action (Elmesky, 2015). Teo's initiative was evidence of a build of up positive EE through IR chains, which manifested as his confidence in starting a conversation in German.

Group D exhibited a higher degree of emotional and linguistic synchrony (Table 3.4). Teo took a very different position relative to his role in directing and initiating science investigations, and in initiating conversations in German. The analysis presented shows that in the prior three Groups, (A, B, and C), Teo made purposeful moves to avoid verbally engaging in German without scripts. In comparison, in this moment in Group D Teo initiated engagement in the target classroom language, German, with the teacher in an unstructured, improvised exchange of conversation about his science observations.

The analysis presents four group investigations as summarised in Table 3.4. From this analysis, we make the claim that the use of ritualised science instructional practices afforded Teo the space to participate in positive IRs, which when experienced repeatedly over time, lead to a build-up of positive emotional energy. He was positioned to participate in different ways regarding his engagement in science practices and use of language resources. Across the four group situations Teo builds upon successful positive IRs, and employed strategies, specifically the repetition of participation rituals, that helped him shift from being an assistant who moved away from interactions in German, to contributing as a director of science investigations and to initiate conversations in German. Video analysis revealed higher levels of synchrony in movement and emotion developed in Group D, the fourth group in which Teo worked (Table 3.4). In addition, Teo initiated an unscripted interaction with teachers in German, a first for him during the study.

Discussion

Recent science education policy initiatives advocate the use of student-driven inquiry-oriented instructional approaches that engage students in the practice of science (NGSS Lead States, 2013; NRC, 2012). These instructional approaches position students to actively participate in designing and conducting science investigations, and through these processes, to actively participate in the learning and doing of science. In order for these instructional approaches to provide students with learning opportunities, it is crucial that students have the means to participate fully in such practices. Students who are language-learners run the risk of missing opportunities for meaningful engagement when they are required to participate through languages they have not yet mastered (Wellington & Osborn, 2001). While research has documented that hands-on inquiry-based science is a meaningful context for language development (Lee et al., 2005), language can also act as a barrier that impedes student participation and thus instructional approaches that reduce this barrier should be employed (Lee et al., 2013; Wellington, & Osborn, 2001). To successfully support instruction that reduces language barriers for all students, it is essential to understand students' access to language resources in interaction when participating in science investigations, and how access to these resources intertwine first, in their engagement with group-members and second, with the practices of science.

This study analysed the case of a plurilingual student who worked within four different small-group investigations (Groups A, B, C, and D) over a period of six months. Through his work in these groups, he was expected to engage in science practices and communicate his findings in German, a language he had avoided using in past interactions with teachers. Video analysis revealed different degrees of synchrony developed at micro-levels in interaction within each of the four groups. Group A had the lowest level of positive IRs form, and very little synchrony. This was followed by the development of offset synchrony in Group B. In Groups C and D, greater levels of synchrony developed (Table 3.4). Video analysis at meso- and micro-levels illustrated how the positive EE that developed led to an increase in Teo's confidence, resulting in his initiative to seek out conversations with teachers in German.

Two claims arise from this analysis. First, pedagogical approaches that contain ritualised components created environments that mediated the formation of interaction rituals at the micro-level. In the specific case presented in this study, the use of the same student-driven inquiry-based practices (posing questions, designing and conducting investigations, communicating results) over four different cycles, created repeated opportunities for Teo to engage in and become familiarised with these processes.

The second claim that arises from analysis is that the interaction rituals that formed on the micro-level within the space of these instructional approaches resulted in the build-up of positive emotions and synchrony in small-groups (less in Group B, more in Groups C and D). The positive interaction ritual chains that formed afforded Teo opportunities to develop synchronous practices with his group-mates, students who were more confident interacting through the use of German. This in turn mediated his engagement in ways that increased his meaningful participation in science practices and in his use of German. Moreover, this study shows how in each of the four groups, that consisted of different constellations of students, Teo employed the same *participation rituals* (namely repetition and positing himself to silently participate), which when successful, built positive emotional energy that assisted him to initiate conversations in the language of instruction.

While this study has shown that ritualistic ways of engaging in science instruction in the context of inquiry-based instruction supports participation in ways that foster synchrony and positive emotion in small groups, the question could be asked, was Teo's participation different because he worked with different groups of students in each of the four groups? While this should be considered, we do not attribute the findings to this. Unstructured interviews with the teacher revealed that Teo had worked with different constellations of students in this classroom over the course of two years. Thus, Teo had experience working within different student groupings, and yet and at the time of this study, Teo had not initiated conversations in this the ways observed in this analysis, in German.

An additional aspect of Teo's participation that could be questioned was his familiarity with the Luc and Neal, his partners in Groups B and C. It could be inferred that perhaps he was closer with them, or felt more comfortable with them, and thus this along with the ritualistic components of the instructional method, assisted his participation. While this is certainly a factor, we point out that analysis revealed different forms of synchrony developed in his work with these same students in Group B than in Group C. This supports our claim that the structure of the spaces in afforded Teo the room to interact in micro-ritualistic way that developed into more synchrony over time. Conducting further research to explore if this same pattern of interaction developed for similar students in similar contexts would help explore this issue.

This study thus shows, that ongoing opportunities for the generation of positive emotional energy can lead to sustained participation in a community of learners, that then leads to learning. This is supported by the recent study by (Olitsky, 2017) in which the development of synchrony on micro-levels among professional teaching communities mediated their ability to work across cultural differences, In a similar way, Teo was able to work across through his language differences toward full participation in the classroom. This led to him taking on a central role in directing science investigations, and to increase his initiating of conversations in the language of instruction. Daugaard and Laursen (2012) in their research in multilingual classrooms explain that, “doing and learning (science) literacy is not only about mastering a code but also about knowing how to participate in language and literacy practices that are valued and recognised as legitimate” (p.105). In this way, Teo was able to increase his science literacy, which were afforded through the use of ritualised instructional approaches.

Implications

This research suggests that the use of student-centred inquiry-oriented instructional practices, as were used in this study, afford students opportunities to cultivate ritual science practices on meso-levels, that in turn allow for the cultivation of interaction rituals chains on micro-levels that effect student participation and resource access. These findings have implications for educators in that they demonstrate pedagogical approaches that create space for multiple languages in flexible ways. Additionally, they allowed Teo to experience successful interaction in various ways and through different forms of material and social support, and through these varied participation approaches he could experience success using the language he was working to master. Thus, allowing these resources to be included in the generation of successful interaction rituals expands the notion of what can be “included” as resources in the creation of interaction rituals on the micro-level and learning strategies on the meso-level.

Interaction rituals come together as chains that are repeated over time, which form a basis for group membership. This study builds on a body of research (Elmesky, 2015; Olitsky, 2017; Olitsky & Milne, 2012) that shows the value of analyzing student engagement in science as collective engagement situates the learner as a part of a collective. We support the view argued by Olitsky and Milne (2012) that "participation is an outcome of collective emotion generated in interaction rituals" (p.18). This pushes back at work that assigns learning to the individual. We view Teo's engagement in science practices as a property of the interaction that occurs between him and his group mates (Bellocchi, 2017), which cannot be ascribed solely to Teo as an individual.

Prior research on interaction rituals in science classrooms has shown that the generation of successful positive IRs affects students' participation in whole-class activities (Olitsky, 2007). Further, if teachers become attuned to the IRs and IR chains, be they positive or negative, they can work to adjust their teaching practices in ways that lead to increased student participation (Elmesky, 2015). The research we present herein has additional implications for educators working to incorporate student-centred pedagogical approaches, in that it underscores the importance of time when implementing pedagogical structures that engage students in actively in designing and conducting science investigations. If we had examined Teo's participation in only Groups A and B, we would not have seen his transition from silent to verbal participation. Verbal participation in the language of instruction that resulted in a build-up of positive emotional outcomes took time. It is essential that teachers and education policy makers are aware that students may require time to build successful skills necessary to participate in student-centred and language-rich instructional practices.

Bellocchi (2017), in his elaboration of the use of interaction rituals as a lens to examine science learning, suggests that scientific practices and ideas can be seen as *emergent and contingent realities*. This research shows the emergence of Teo's science practices and language use on both micro- and meso-levels of interaction, and as embedded in, and contingent upon interaction rituals that formed within the investigation groups. This study further showed how Teo's participation in science practices became more elaborate as he was able to build upon successful interactions that lead to collective group success.

While this study focuses on the interactions in a multilingual class, we stress the importance of understanding how students interact in ways that not always conscious, but that never-the-less have a direct impact on their ability to participate in instructional activities, and through their participation, form successful learning rituals. This understanding is key for all students and teachers, be they multilingual or monolingual, in that language plays such an important role in mediating students' participation and engagement in science instructional activities, and if students are barred from participating, they will not have the opportunity to learn.

CHAPTER 4

THE PEDAGOGICAL POTENTIAL OF SCIENCE NOTEBOOKS IN INTERACTION

Abstract

This study examined the use of science notebooks in interaction in the context of inquiry-based science instruction in a multilingual classroom. The research presented first examines students' construction of notebook entries over the trajectory of an inquiry-unit, and second, analyses key interactions surrounding the use of science notebooks while students work in small-groups during a culminating activity. Analytical maps depicting the trajectories of students' notebook entries over the course of the unit were used as the basis for selecting episodes for multimodal interaction analysis, and for the identification of focal interactions between students, peers, and teachers. Three detailed cases of notebook use during small-group work are presented. Analysis of focal interactions reveals students' dynamic use of the semiotic space in and surrounding the notebooks. The framing and subsequent use of the notebooks in this multilingual classroom during inquiry-based instruction afforded students space for fluid language use, and semiotic resource use, processes that were not always apparent to the teachers, or documented in the notebooks. Pedagogical opportunities for science notebook use, in particular in multilingual classrooms, are discussed.

Keywords: student science notebooks, multimodal interaction analysis, multilingual, inquiry-based science

Introduction

Key science education policy documents call for science instruction that engages students' in the practices of science (Lead States, 2013; Léna, 2009; NRC, 2012; Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, & Hemmo, 2007). While science instruction that supports this can be formulated in a variety of ways, it requires that students participate and interact in classrooms in ways that are different than those required during transmission-based forms of science instruction. Active engagement in science processes, such as through inquiry-based science instruction, can position students to question, to investigate, to collect evidence, and to think critically as they develop science understandings (NGSS, 2013). Science notebooks can support students in working in these active, inquiry-based manners of learning. When students have the opportunity to use science notebooks to document their investigations in rich and meaningful ways, the notebooks can support students to build not only science understandings, but also understandings about how to engage in science practices that unfold in interaction. To gain a clearer understanding of the ways in which students engage with science notebooks, and their pedagogical potential, this study analyses the use of science notebooks in interaction in a multilingual classroom engaged in inquiry-oriented science instruction.

Theoretical grounding

Science notebooks as an important instructional tool

Previous research studies have established that science notebooks, when used as a place for documenting students' thoughts, ideas, and investigations, can serve as a powerful instruction and assessment tool (Huerta, Tong, Irby & Lara-Alecio, 2016;

Klentschy, 2005; Ruiz-Primo, Li, Ayala & Shavelson, 2004).When used in ways that support teachers and students in going beyond the documentation of teacher-transmitted information, science notebooks provide a place for students to record their science ideas and understandings, making them visible to both teachers and to their peers (Butler & Nesbit, 2008; Campbell & Fulton, 2003; Wiebe, Madden, Bedward, Minogue & Carter, 2009). In the context of inquiry-based science instruction, the use of science notebooks can provide space for students to construct entries that draw upon a range of genres (Shepardson & Britsch, 2001), and that reflect students' engagement in the practices of science (Wiebe et al., 2009). When students are encouraged to revisit their entries and revise them over time, science notebooks can assist students in developing an understanding of the *nature of science* as dynamic and the ways that understanding can change over time in ways that parallel how science is conducted by scientists (Butler & Nesbit, 2008). From an assessment standpoint, they can be used as a tool that reveals students science understandings in the course of instruction (Aschbacher & Alonzo, 2006). While the potential benefits of science notebooks use are well documented, studies have additionally shown that science notebooks often are implemented in ways that only engage students in low-level science tasks, such as documenting science vocabulary (Ruiz, Li, Primo & Shavelson, 2002). This means there is potential to expand how science notebooks are used in classrooms in ways that support students' engagement in higher-level science practices.

Research on the use of science notebooks with language learners, such as is the case in this study, has shown that notebook use that provides spaces for students to write and then discuss their own notebooks with peers is beneficial for both written and spoken language development. Haneda and Wells (2010) conducted a descriptive study that demonstrated the ability of science notebook writing to support collective thinking with language-learners. Their study illustrated how individual notebook writing served as a starting point for group discussion. The individual writing drew upon individual *intramental* thinking that then was transferred to *intermental* group thinking when notebook entries served as a basis for group talks that followed. In this sense, the notebook provided a transitional space, moving students from individual thinking to group thinking, and from individual writing, to group speaking. The science notebooks thus served as an important space that supported both science learning and literacy development.

To date, research on the use of science notebooks has primarily utilized analytical approaches that examine students' notebook entries as static texts. In this way, analysis has prioritized the texts over the interactions and decisions that led to the production of the texts (Chandler, 2007). This study expands these views, through analysis that examines not just students' notebook entries as texts, but analysis of the interactions and decisions that surround the construction of the entries. In doing so, this study provides a more comprehensive analysis of notebook use that aligns with contextualized, interactional views of science and science learning, and contributes a much-needed view of science notebook use in interaction.

Science classrooms as semiotic social spaces

Semiotic theoretical perspectives can be used to view student science notebooks as rich repositories for *representing* and *communicating* the diverse semiotic signs present in science learning spaces (Jewitt, Kress, Ogborn & Tsatsarelis, 2001). The study I share here employs post-structural semiotic lenses that situate meaning making in classroom spaces as social and dialogic (Kress et al., 2001). This means the theoretical perspectives I draw upon in this study view semiotic resource use in classrooms, by both teachers and students, as social, contextualized and emergent in interaction (Bakhtin, 1981; Halliday, 1967; Kress et al., 2001). One way to view semiotic resources use is through the use of multimodal perspectives of learning in general, and science learning in particular (Kress, et al., 2001; Norris, 2004). In this study I draw upon multimodal lenses to examine semiotic resource use during science learning. I do this in order to examine the processes that emerge in interaction between students, teachers, and notebooks as they participate in the *doing* of science in the context of an inquiry-based science unit. (Siry, Ziegler & Max, 2012).

Multimodal views of science classrooms, such as those used in this study, assume that language plays an important role in science classroom interactions, but contrary to research approaches that place language at centre-stage, multimodal perspectives situate language as *one* of *many* communicative and representative resources employed by students and teachers (Kress, Ogborn & Martins, 1998; Zhang, 2016). The semiotic resources used in classrooms are abundant and include language, gaze, body position, gesture, image, sound, spatial orientation, and movement (Kress, 2001; Norris, 2004; Jewitt, 2009). Through different combinations of these resources, their use unfolds in interaction, as teachers and students orchestrate meaning (Jaipal, 2009; Kress, 2001; Márquez, Izquierdo & Espinet, 2006; Delgado & Moje, 2014). It is from this multimodal semiotic stance that this research views the use of student science notebooks in an inquiry-oriented unit on condensation and evaporation.

Science notebooks as semiotic social spaces

To view science notebooks in use, this study employs Gee's (2005) notion of semiotic social spaces as a theoretical lens. Semiotic social spaces (SSS), Gee explains, are places where social actors interact in the use, exchange, and transformation of semiotic resources and signs. I apply this notion to view science notebooks and their use in classroom contexts.

The theoretical perspectives that ground this study do not assume that the relationship between signifier-signified is one-to-one. On the contrary, it assumes that there exist a multiplicity of meanings that can be conveyed and received, depending on the perspectives of those interacting in the semiotic social space, and depending on how semiotic resource use unfolds in interaction (Bakhtin, 1986). Thus, the views afforded by this research support views of science learning that go beyond views during which students need to decode the correct signal transmitted by teachers as discussed by Elmesky (2011) and Seiler (2011). Instead, through the analysis I present in this study, I work to tease apart how semiotic resources are used in interaction among students, peers, and teachers during learning that is student-driven, and that makes space for multiple voices in the learning process.

I now return to Gee's notion of semiotic social spaces (2005) to further identify key aspects of SSS and to elaborate how they guided the analytical lenses used in this study. SSS can be viewed, examined, and analysed from both internal and external perspectives. Gee (2005) elaborated this approach in his analysis of multiplayer videogames and online interfaces that allow for multiple user interaction. To examine an SSS from an *internal* view is to examine the content that the space contains. In other words, internal views reveal the ways in which content is treated in the space and how that content is represented. Thus, applying this conceptualization of SSS to the notebooks analysed in this study, an internal view is used to examine the content that is represented by actors (students and teachers) within the semiotic space (the notebook and classroom). An internal view provides one perspective from which to view the use of semiotic resources employed in the notebooks. To date this has been the approach most often utilized in the field of science education research and involves analysis of the representations and forms of science notebook entries (see for example Wiebe et al., 2009). Past analysis science notebooks in line with views of the internal perspectives of the semiotic space, have shown, for example, that there often exists a "disconnection between teacher discourse and student discourse" (Ying Zhan6, 2015, p.7). In her study, English Language Learners (ELLs) were asked to construct of drawings in their science notebooks following a science teacher's multimodal presentation. The study showed that even though the teacher employed multimodal instructional methods, the students constructed notebook entries depicting understandings that were different from the teacher's. This study aims to move beyond examining only internal views of notebook representations and entries, to analyse both *internal* and *external* views of notebook use. Through analysis of both these views, this study aims to reveal how the notebook can be positioned in instruction to support inquiry-based learning goals (NRC, 2012) and students' participation in authentic science investigations (Rivera Maulucci, Brown, Grey & Sullivan, 2014). But first, I elaborate the view of representation assumed in this study.

This study is situated in Bakhtinian (1981; 1986) views of semiosis as multiple, and contextualized. The analysis of notebooks presented herein examines how students and teachers use and interact within the semiotic social space. This study extends prior studies rooted in semiotic views of science classrooms with the aim of providing rich views of semiotic resource use as it unfolds in interaction in multiple ways. The views afforded by this research support views of science learning that go beyond views of learning as a process by which students decode signals that are transmitted by the teacher (Elmesky, 2011; Seiler, 2011). Instead it works to tease apart how semiotic resources are used in interaction among students, peers, and teachers during learning that is student driven

A second essential perspective of SSS is to view them from an *external* view. External views allow for an examination of the way participants, tools, and materials in semiotic social spaces "think, act, and interact" (Gee, 2005, p.28). In this study, an external view of science notebooks means to examine the notebooks viewing the ways in which notebooks, students, and teachers "act and interact" (Gee, 2005, p. 28) in the construction and use of the space (the notebooks). It includes analysing how the space (the notebook) is designed and used in interaction, and how this design mutually informs the type, form and shape (in both substance and form) of the content produced in the space (the notebook). Through a consideration of both the internal and external views of the notebook as SSS, views are afforded of not only the content of notebook entries, but also of who is allowed to act in this SSS, and how they are allowed to act. Thus, a much more situated, unfolding-in-interaction view is afforded of the use of the notebooks that does not reduce the notebooks, and the representations they contain, to views as static texts.

The relationship between the external and internal views of the semiotic social space is direct and dialogical. External interactions among participants in the SSS and through the use of the space determine what is used, what is allowed, and what is constructed in the content of the internal components of the space. Thus, "the relationship between the internal and external is reciprocal" (Gee, 2005, p. 29). This has important implications for how science education research views semiotic resource in classrooms in general, and in and through the use of science notebooks in particular. When viewed through both internal and external views, and in teasing apart the relationship between the two, views are afforded of not just the content that is represented in the notebook, but the interactions and decisions that produce and reproduce semiotic resources within the space.

In this study, multimodal interaction analysis (Norris, 2004; Rowe, 2012) is used to examine semiotic resource use in students' science notebooks from both internal and external views (Gee, 2005). First, students' notebook entries are analysed using methods rooted in visual semiotics (Kress & van Leeuwen, 1996) to view how students constructed entries across the trajectory of the inquiry-based unit. Then, an external view of the notebook in use in interaction with students, peers, and teachers is layered onto the internal view. Combining these two views in analysis allows this study to build on prior research that examines semiotic resource use in science classrooms through time in ways that provide a more robust view of the interactions that produced the entries (Jaipal, 2009; Tang et al., 2014; Zhang, 2016). This analysis leads to claims about the pedagogical potential of the notebook use in interaction in classroom contexts.

While research has been conducted exploring the interaction of semiotic resources in representation and communication among students and teachers in their construction of scientific understandings (e.g., Márquez et al., 2006; Tang et al., 2014; Zhang, 2016) there exists a dearth of analysis of science notebook use in interaction. To contribute an understanding of the use of science notebooks in interaction, this study explores the characteristics of notebook use in this inquiry-based multilingual classroom and explores the questions,

i. How does the teacher structure students' use of the notebooks?

ii. How do the students use the notebook to document during inquiry-based instruction?

iii. What do science notebooks, when viewed as a semiotic social space, enable in terms of representation and communication in interaction with students, and teachers?

To address these interrelated questions, this manuscript (Chapter 4 in this dissertation) presents three detailed cases of notebook use from a multilingual classroom engaged in inquiry-based science instruction. Cross case analysis reveals views of science practice engagement, and language resources that are fluid, complex and unfolding in interaction.

Methods

This study was a subset of a larger research project that examined the use of an inquiry-based science approach in multilingual elementary classrooms in Luxembourg. Science Workshop, the instructional approach supported teachers in using an integrated inquiry-based science and language approach to instruction in multilingual classrooms in Luxembourg. For a detailed description of the project see Wilmes (2016) [12]. The instructional approach supported teachers in creating instructional spaces for students to engage in science practices through dialogic instructional approaches (Haneda & Wells, 2010) and student-driven science investigations.

Study Context

Inquiry-based science instruction. The research presented in this manuscript focuses on a subset of data from a larger data corpus collected during an overarching study. Analysis presented in this chapter zoomed in on one inquiry-based science unit (The Water unit), which engaged students in inquiring about condensation and evaporation (Refer to Chapter 3 for an overview of all three inquiry-based units used

[12] Wilmes (2016) refers to Chapter 2 of this dissertation.

with this class). In total, the unit consisted of five two-hour sessions of inquiry as detailed in Table 4.1. Inquiry experiences consisted of two cycles of students posing questions about science phenomena, designing and conducting investigations to explore their questions, and communicating their findings and understandings (Minner, Levy & Century, 2010; NRC, 2000). The unit was designed to engage students in science in dialogic ways (e.g., Wells, 2000) through inquiry-oriented units that provided spaces for students to ask questions that guided investigations (Wilmes, 2016). Students first read a story about children camping (Konicek-Moran, 2008). While camping, the children were sleeping in a tent when, suddenly, droplets of water fell on one of them. This scenario was presented on Day 1 to engage students and prompt discussion of the reasons for the condensation (droplets of water). Students then generated questions to explore the possible reasons for the droplets, which served as a starting point for student-designed science investigations.

	Day 1	**Day 2**	**Day 3**	**Day 4**
Science activities	• Introduction to the unit: presentation of tent mystery • Use of the science notebooks introduced • Small-groups plan an investigation to test questions about the droplets in the tent	• Small-groups conduct first investigation	• Small-groups conduct second investigation	• Students individually write in the notebooks, "My best understanding so far is…." • Small-groups discuss what they understand about the droplets in the tent
Notebook task	• Construct an investigation plan	• Record what happened in your investigation	• Make notes about what happened in your second investigation	• Write, *My best understanding now is…*and draw your understanding

Table 4.1. Overview of Water inquiry-based unit

School and classroom. This research took place in Luxembourg, a country with a trilingual school policy. The analysis I present in this manuscript zooms in on notebook use in a fourth-grade class in an urban primary school in Luxembourg City. The class consisted of 14 ethnically, social-economically, and linguistically diverse students (10-11 years old). Nation-wide approximately 44% of the Luxembourg public school student body identifies as being a nationality other than Luxembourgish (STATEC, 2015). This diversity, considered in combination with the tri-lingual education system, results in classroom contexts in which many students are working in language(s) other than their first-language.

Participants. Of the 14 students we worked with, all 14 were multilingual in a myriad of combinations, not just in Luxembourgish, German, and French. It is this linguistic diversity that prompted the research project to investigate semiotic resource use in interaction, as the communicative complexity of this classroom provided opportunities to investigate the range of semiotic resource use – not just linguistic – employed when students engage in inquiry-based science instruction and used science notebooks during inquiry processes. The linguistic profiles for the participating students are detailed in Appendix B. I mention this to underscore the diverse linguistic resources composing the linguistic repertoires of each participating student. It is important to the claims that arise from analysis, that the students at the focus of this study are heard speaking and seen writing in two languages, Luxembourgish and German, even though only two students, Roberto and Nia, have these as home languages.

Teachers. Members of our research team, Chris, Jana, and myself, co-taught the class with the classroom teacher. This allowed us to work together collectively to support the inquiry instruction as it unfolded and to participate in the instruction (& Roth & Tobin, 2004). It also afforded us roles as participant observer (Atkinson, Coffey & Delamont, 2003), roles from which we could draw upon during later video and notebook analysis.

Data collection

The data corpus at the focus of the study presented in this chapter was collected as a part of a larger project conducted Luxembourg from 2014 through 2015. As the study is grounded in poststructuralist views of semiotic resource use, it is my view as Chandler (2007) states, that "We cannot stand outside of our sign systems" (p. 218). Thus the multi-layered data corpus incorporated multiple layers and perspectives (Zhang, 2016) that captured my own, and my research team's, perspectives of the interactions at multiple points in time during data collection and analysis. The subset of data analysed for this study consisted of:

- Whole-class video recordings: were recorded to "account for all of the semiotic resources that the children and teachers brought to bear during the science investigations" (Britsch, 2009, p.214).
- Small group video recordings: captured multimodal interaction in small-group tasks and for additional perspectives when compared with whole-class recordings.
- Audio recordings of students explaining their ideas: were collected when a teacher (Chris) visited groups and as they worked, asked recorded students ideas. These "on-the-spot" conversations provided students thoughts, impressions, and insights as they worked, (Cowie, Otrel-Cass, Moreland, Jones, p.87).
- Student science notebook entries: were constructed by students to record their questions, investigation plans, and thinking. These provided a rich source of data in narrative and representational form of students' interests (Kress, et al., 2001) and inquiry investigations. The nature of entries is elaborated in sections that follow.

- <u>Descriptive field notes</u>: were constructed to capture situated impressions and thoughts immediately following classroom (Emerson, Fretz & Shaw, 2011).
- <u>Student focus group interviews:</u> were conducted at the culmination of the condensation and evaporation unit to capture student's thoughts and impressions and details about students' linguistic repertoires.

Data Analysis

Sociocultural perspectives of semiotic spaces and sign production in interaction ground this study (Gee, 2005; Norris, 2004). The analysis presented here considered the histories, practises (Scollon & Scollon, 2007) and resources students and teachers bring to these interactions, and how they intersect in use when students and teacher interact, use, and talk around the use of their science notebooks. Methodologies that analyse just the spoken or written are incomplete methodological approaches (Jaipal, 2009). As Norris (2004) explains, "All interactions are multimodal" (p.1). This study utilized methods rooted in multimodal analysis of students' and teachers' situated practices to examine intersemiotic relationships in a classroom context (Jewitt, 2009; Kress, 2010). To examine both the internal and external views of semiotic resource use, exchange, and interaction in and around the science notebooks, this study uses multimodal interaction analysis (Rowe, 2012; Norris, 2004) along trajectories of the inquiry-based unit. Analysis examined notebooks from two interrelated perspectives, internal and external, to provide a layered view of the notebook as a semiotic social space. The first layer established an internal view of the representations contained in the notebook entries. The second layer was used to illuminate external views of the notebooks in use and thus analyse student and teacher interactions surrounding the use of the notebooks. The analysis I present in the sections that follow detail these two interrelated layers and draw claims from the consideration of both.

Phase I Analysis: Students' use of the science notebooks to document inquiry. Semiotic analysis was employed in phase I to examine students' notebook entries (Kress et al., 2001; Kress & Van Leeuwen, 1996), specifically to categorize the content and form of students' notebook entries. Three entries from the inquiry-based unit were analysed as complete class sets of these three tasks were obtained for all students (14 total). Initial analysis involved noting the form and content in entries and through a process of grounded analysis (Bogdan & Biklen, 1982) led to the development of categories that were then subsequently used to categorize the genre, form, and content of all three tasks for all 14 students. These are shown in the table that follows.

Table 4.2. Categorization of student notebook entries

For all entries

A. Source of information conveyed: Students constructed responses that consisted of information drawn from the four following categories,
   - Experienced – lived experiences occurring outside of the classroom
   - Story-related –information drawn from the tent story
   - Investigative – information drawn from class science investigations
   - Imaginative – imaginative information

B. Framing of entries: Techniques students used on the notebook page to segment an idea, representation, or narrative from other ideas. (Categories included, by page, using lines, using boxes, other)

For written representations

C. Tense: When students wrote they used different tenses during different genres of writing which included: 1st person (I), 2nd person (you), 3rd person (One, he, she), 4th person (we) and fifth person (They)

D. Form of written: labels, phrases, sentences

E. Language resources incorporated**:** German, Luxembourgish, French

Notebook trajectories. All 7 – 12 entries for each student were placed in a trajectory. This provided an overview of students' mode choices over the course of the notebook entries for the water unit. These trajectories provided further insight into students' entry choices, and subsequently served a basis for Phase II analysis. From these trajectories, students were placed on a continuum of those who selected more written versus those who selected more drawn modes in their entries. From this continuum, three students, one from each end and one from the middle, were selected for Phase II analysis.

Phase II Analysis: Science notebook use in interaction. The second phase of analysis situated the notebook as not just a receptacle in which students deposit representational information through the construction of texts or *frozen* modes (Norris, 2004), but as a tool around which action occurred. Interaction analysis was employed to explore the modes students attended to and employed in interaction with notebooks, peers, and teachers in the space of the classroom (Norris, 2004; Rowe, 2012). This second phase of analysis began with first selecting key students to focus on based on their notebook trajectory constructed in Phase I. This led to grouping students on a continuum based on their use of more written or drawn modes in across their entries for the entire unit, not just the three tasks. From these, a process of continuum sampling (Patton, 2015) was used to select a student who constructed mainly written representations, a second student who constructed mainly drawn representations, and a third student who fell in the middle of the two ends of this continuum. This allowed for an examination of the different ways students were utilizing text and drawing, which was particularly interesting given the diverse linguistic repertoires of the students. Next, multimodal video analysis coupled with science notebook analysis was used to construct three cases, one for each student group as they worked during a twenty-five minute period of instruction on Day 4. During this specific task, students were asked to discuss their understandings with their group, and record them in their notebook. This period was selected as students had constructed two rounds of investigations and the student-driven portion of the unit was drawing to a close. Additionally, Chris interviewed student groups as to their understanding about the droplets in the tent, providing an additional layer of perspectives to video analysis.

Next, video analysis was conducted to construct notebook trajectory maps for each student small group. These showed the sequential development of the multiple notebook entries produced and referenced during the twenty-five minute task by each student in the small group. These maps then served as a basis for additional rounds of multimodal interaction analysis (Norris, 2004). Video analysis for each of the three groups was conducted to identify focal interactions. Focal interactions in the context of this study, are defined as interaction "linked by thematic continuity" (Garvey, 1984, p. 79) involving this notebook task. Once key interactions were identified, multimodal transcripts assisted for each focal interaction, and were composed of action, spoken, postural, proxemics resources used in focal interactions. The multimodal transcripts for focal interactions were then used for case development, followed by cross-case analysis (Yin, 2014). Throughout this process, all analysis was shared with other researchers multiple times to verify the themes that emerged in analysis.

Layering Phase II interaction analysis onto the analysis conducted in Phase I allowed the research presented here to move beyond views of science notebook use that "subordinate other moments to textual analysis" (Johnson, 1996, p. 98). This study presents analyses of both the texts and the interactions involved in their construction and thus provides a more robust interactive view of semiotic resource use in a science classroom in general, and specifically in the context of the use of science notebooks.

Language considerations

All data sources were analysed in their original language. Transcriptions for all focal interactions were additionally recorded in their original language. Translation into English was done for presentation and manuscript purposes as a last step. Researchers fluent in combinations of English, German, and Luxembourgish conducted translations. Communication between the researchers/co-teachers and the students during classroom activities and student interviews took place using German. Two of the three members of the research team were fluent in German, and also able to understand and converse in a high level of Luxembourgish, thus helping to ensure the translation and communication during instruction, and interviews proceeded with a high degree of accuracy.

Analysis

In the sections that follow, I present first the results of Phase I analysis, onto which I then layer Phase II analysis for the three case studies developed of small-groups working with science notebooks during a twenty-five minute task on Day 4 of an inquiry-based science unit.

Phase I Analysis: Students use of the notebook semiotic space

Phase I of analysis addressed the first and the second research questions, how did the teacher structure notebook use and relative to this, how did the students use the notebook to document during inquiry-based science instruction?

Teachers' structuring of notebook use. We introduced the use of the notebooks during the first inquiry session (Table 4.1, Day 1). The initial task we posed was "Design an investigation" in which students constructed an investigation plan to explore their questions about the water droplets falling on the children inside of the tent. Students were provided with sheets of paper to use for notebook entries, which were collected in binders for each student. This framing of the notebooks use is key to the analysis I presented next, as Gee (2003) explains, "Who designed the space and with what goals in mind, helps in revealing the principles, patterns and procedures that went into the construction of the semiotic social space" (p. 32). This was the first time this class had used a science notebook in an open manner. In prior science lessons with their classroom teacher, notebooks served as a place to record science facts. In this way, in previous lessons outside of the context of this study, notebooks were used as a space to document canonical science understandings, in contrast to being a space for students to express their diverse understandings, perspectives or views.

All notebook tasks across the four days were initiated by the teacher, but were student-driven in their construction. This meant that students were able to decide how to construct the entries. This differs from notebook entries that are structured by a teacher-selected heuristic (see for example Burke, Greenbowe & Hand, 2006). In the instruction analysed in this study, students selected the form of their representations as written, drawn, or combinations of both, and which language resources they utilized. On Day 3 they were also given an opportunity to take photos to document their investigation.

Students' notebook entries. Table 4.2 shows result of analysis of the three notebook tasks. Results of Phase I analysis show that students selected a wide range of representational means within each task. The majority of students selected a combination of written and drawn modes. A summary of the frequency of students that selected each, by task, and lists of fuctions of the written, and representational are summarized in Table 4.2. Entries were compared within small-groups for form. It is interesting that some groups exhibited great diversity in what they recorded. While others were quite similar.

Analysis showed that overall students selected both written and representation more often than selecting one or the others (Table 4.2). For entires in which students included both written and dran information, I compared the information contained in each. At times there were overlaps, and at time there was information contained in one mode that was not contained in the other. In this way, the synergy of the use of both expressed more information than the use of either alone. Analysis showed that choice of mode did not correspond with more complete or correct science understandings. Meaning, students who wrote more narratives did not necessarily have more accurate science content in their entries, and vice versa. For this reason, this study can not draw conclusions about a type of mode and the correctness of science understanding. More accurately, choice of mode was attributed to the students' interests at the time of constructing the entry (Kress, et al., 2001) and not to the students' understanding of the droplet phenomena in the tent. While I attempted to categorize types information carried by both written and drawn modes, I found that more often than not, it was not possible to identify the source of the information or to attribute it to a specific category. For example, in a representation, a student drew droplets of water. It was impossible to know if the droplets came from the information provided in the original story, or from their investigation. More likely than not it could be attributed to both. Because of these overlapping and intertwined ideas, both regarding science processes and regarding the tent story, it was not possible to reduce them to coded semiotic chains, nor to even tell if they arose during the course of this unit, or during a different timeframe.

Table 4.2. Analysis of three students' notebook entries from the Water IBSE unit

Task 1: Make a plan in your notebook to investigate a question about the tent (Genre: Investigation plan)	**Task 2: Describe what happened with your investigation (Genre: Investigation report)**	**Task 4: (Describe) What is your best understanding so far…. (Genre: Description of understanding)**
Total written narratives only 2 Total drawn 2 Combination written and drawn 10	Total written narratives only 7 Total drawn 7 Combination written and drawn 7	Total written narratives only 4 Total drawn 0 Combination written and drawn 10
Functions of written • Lists of materials • Labels for materials • Phrases explaining actions to be taken and in order (One or I) • Phrase indicating there is a question • Phrase stating the problem Function of drawn • Depict materials • Depict properties of materials • Depict action to be taken • Depict characters from the story • Depicting information from the story (locations, characters)	Functions of written • List of materials • Phrases and sentences that are: ○ Description of what was done ○ Description of what happened ○ Description of processes (water in the sky) Functions of drawn • List of materials • To show investigation procedure (created during Task 1) • To show what happened in the container (where water collected) • To show themselves conducting the experiment	Functions of written • Description of processes • Location • Order • Properties • Descriptions of storyline • Imaginative • Labelling parts of processes • Playful labelling • Labelling character names • Numbering Functions of drawn • Depicting storylines (characters) • Depicting processes (movement, location) • Depicting perspective (outside, inside tent)

Framing. Students chose a wide variety of framing mechanisms. This varied by student and by entry. Sometimes multiple entries were produced on the same page, and separated by a line or a box. At other times a single page was used to represent one plan, or one idea. Typically, the framing approach used by a student remained constant for the duration of entries across the unit. Analysis showed that students were free to choose a framing strategies, and change these across tasks.

Point-of-view. In constructing entries, students employed multiple points-of-view (first person, second person, third person) for detailing investigation plans, investiation reports, and documenting their understandings. Some students directly referenced themselves, "I will put a straw in the cup. Then I will put hot water in." At other times third person was used, "One puts water in, then covers it." This reflects students' identification as themselves as actors in the processes of science (Kirch & Amoroso, 2016). As with framing, the student's use of a particular point-of-view (first person, third person) tended to stay consistent within a genre, but change across genres.

Notebook trajectories. All entries for each of the 14 students were placed in time-sequence trajectories showing their entries for the entire unit. This revealed further aspects of notebook entry construction across the overall Water inquiry-unit. Trajectories allowed for viewing the three entries that underwent content and mutimodal analysis, as well as additional entries for the entire Water inquiry-based unit. Comparison within the trajectory by student revealed the degree to which students selected more written or drawn modes across all entries. There were students who used writing more than representation, and vice versa. Interestingly, mode choice remained relatively consistent by student across the seven entires. Meaning, if one student selected to draw, and label drawings with one-word labels (lamp, tent, etc), the student tended to use this same this format across a majority of entires. Figures 4.1a and 4.1b on the pages that follow shows notebook trajectories for two students who differed the most in their choice of wrtten and drawn modes over all notebook entries. Their notebook trajectories, shown in Figures 4.1a and 4.1b, are provided as an overview of the views they afforded during analysis. Due to size restrictions, the entries depicted are small. Larger, translated entries are provided in later figures when they support focal interactions presented in analysis.

Phase II Analysis: Science notebook use in interaction

The second phase of analysis zooms in to focus on one twenty-five minute period of instruction on Day 4. Prior to this, students had conducted two investigations, and on this third day, they were asked to first construct individual notebook entries according to the task that follows.

<u>Day 4 Task</u> Describe what you think is happening with the tent. Think back to the investigations, and what you did before, and write down, "My best understanding now is…."

After constructing individual entries, students moved to work in small-groups of two to three students, and to discuss their explanations, adding to their understandings about the cause for the droplets of water in the tent. In the sections that follow, I present three cases, each elaborating analysis of the small-groups' interactions with their notebooks. Within each case, I present analysis of notebook entries along with detailed analysis of focal interactions. Cross case analysis (Yin, 2014) is then presented to compare across groups, and to further elaborate the claims that arise from analysis.

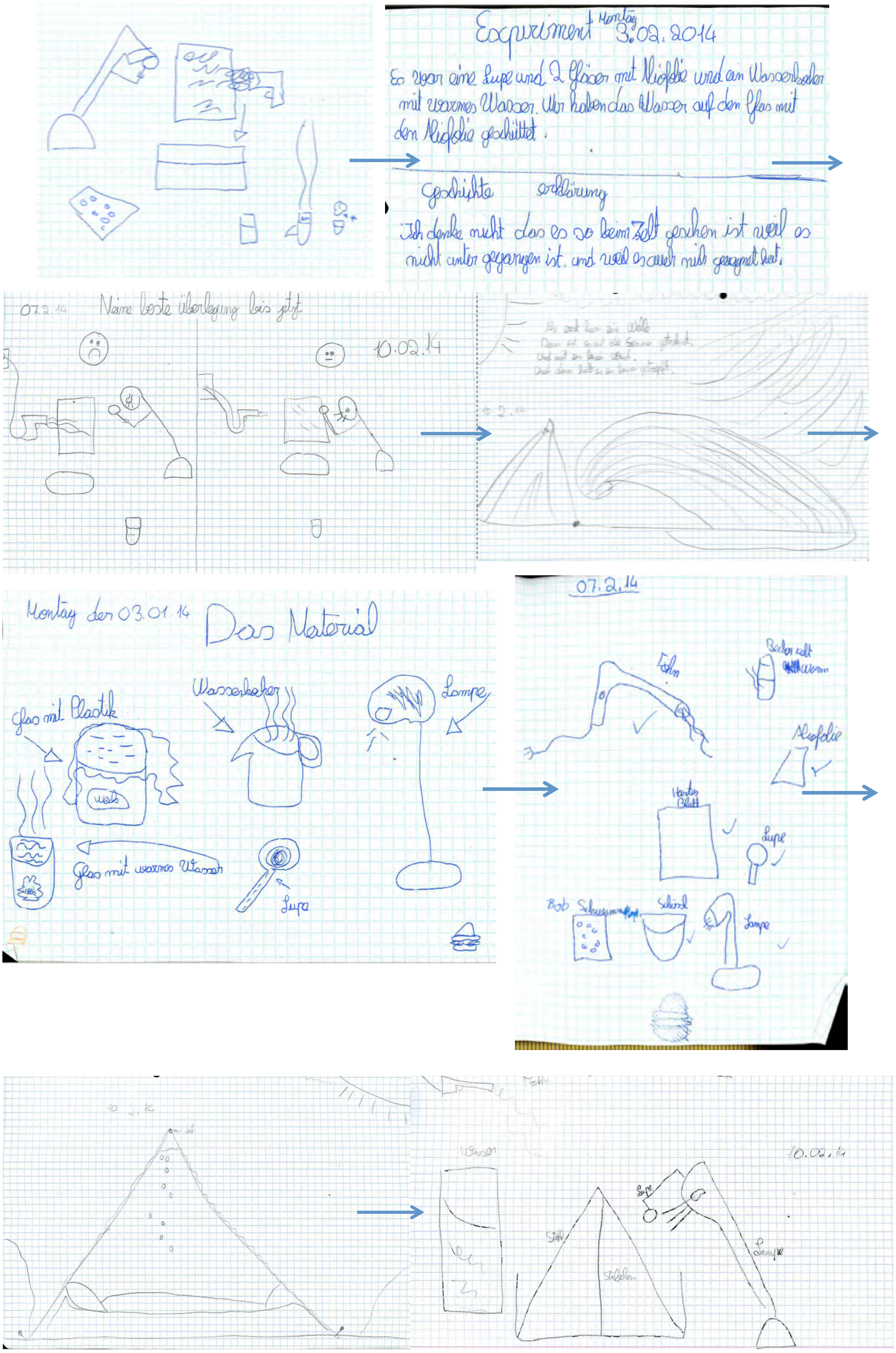


Figure 4.1a. Notebook trajectory for a student who selected drawing as the central mode for constructing entries

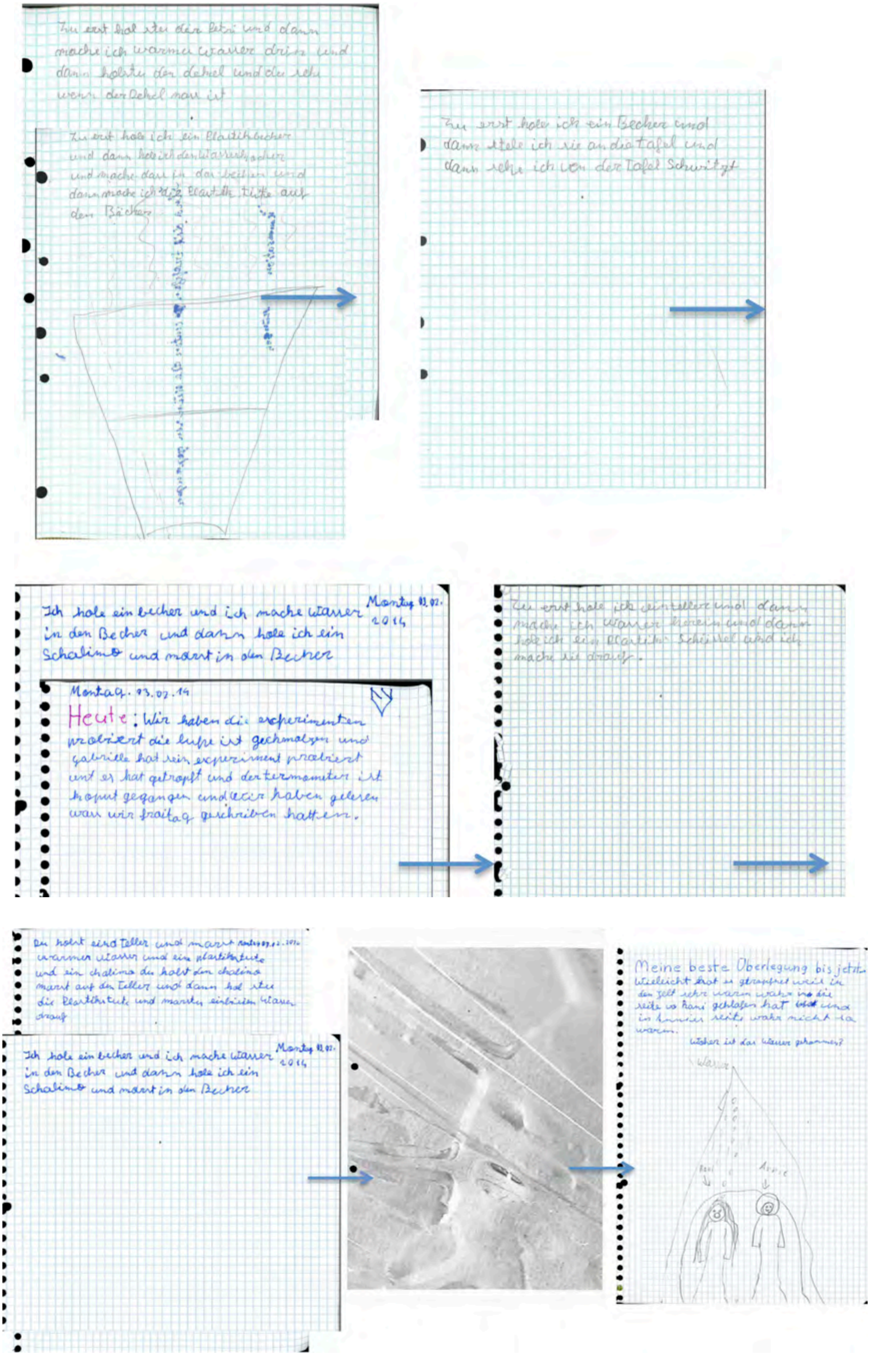


Figure 4.1b. Notebook trajectory for a student who selected writing as the central mode for constructing entries

Case 1: Leo and Hank

Leo and Hank sat at individual desks. Each constructed a representation in their notebooks in accordance with the teacher-framed task to show *their best understanding right now…* and explain in their notebooks their thinking about the droplets of water in the tent. Hank wrote a narrative that stated, "My best prediction right now is that maybe there was a wave nearby, or they ate noodles, or they forgot to dry the tent." (Figure 3, right top). Then he drew three images of tents, each depicting one of the three ideas (Figure 3, right bottom).

Figure 4.3. Leo (left) and Hank's (right) notebook entries.

Leo wrote the title of the task, *My best prediction right now is..* at the top of his entry from the prior session on Day 3. He did this not on a new sheet of paper. Guided by the same teacher-structured task, they each selected different approaches to structure this entry as revealed through the different combinations of writing and illustrations. Leo chose to add to a prior entry and inserted the title of the task at the top of the page. Hank, in comparison, composed a new entry consisting of both narrative and three tent representations showing three possible ideas (N.1 a wave, N2. they forgot to dry it, N3. cooking noodles). His entry revealed he was considering multiple explanations for the cause of the droplets.

Case 1, Focal Interaction A: Creating a collective representation. The teacher instructed the class to move into their small-groups. Hank and Leo sat at the same group table to begin working together. Leo began by calling Hank's attention to his notebook. Leo looked down at his notebook entry and explained to Hank what went well and what did not go so well with his last group's science investigations. Jana came over to the group, and handed them the photos they took last session so they could add them into in their journals. Leo asked Jana for more paper to add more entries into his notebook. He took a new piece, placed on the desk and said, *Okay, Hank…explanations*, while repeating the instructions provided by the teacher, and while laying a new sheet of paper in front of himself on the table.

Leo began drawing, and while drawing asked Hank for a ruler. Hank handed Leo his ruler, and Leo continued drawing. Hank, meanwhile, sat at the table, watching Leo. He gaze was oriented towards Leo's notebook (Figure 4.4). Leo named the objects (wave, tent, sun, clouds) that he drew. Then Hank reached for the pencil (Excerpt 1, line 04) and Leo passed it to him. Hank oriented the piece of paper in front of him, and continued drawing on the same image. Leo tells Hank, *Leave a place for the tent* (line 05). Hank drew lines to represent wind. They passed the pencil back and forth, each contributing a different element to the representation illustrating their idea that the tent became wet as wind caused water from a nearby river to splash on the tent. They passed the pencil, and the role of illustrator, back and fourth three times, with very brief verbal exchanges. They sat focused on the image in front of them they collectively constructed the entry in the notebook (Figure 4.4c).

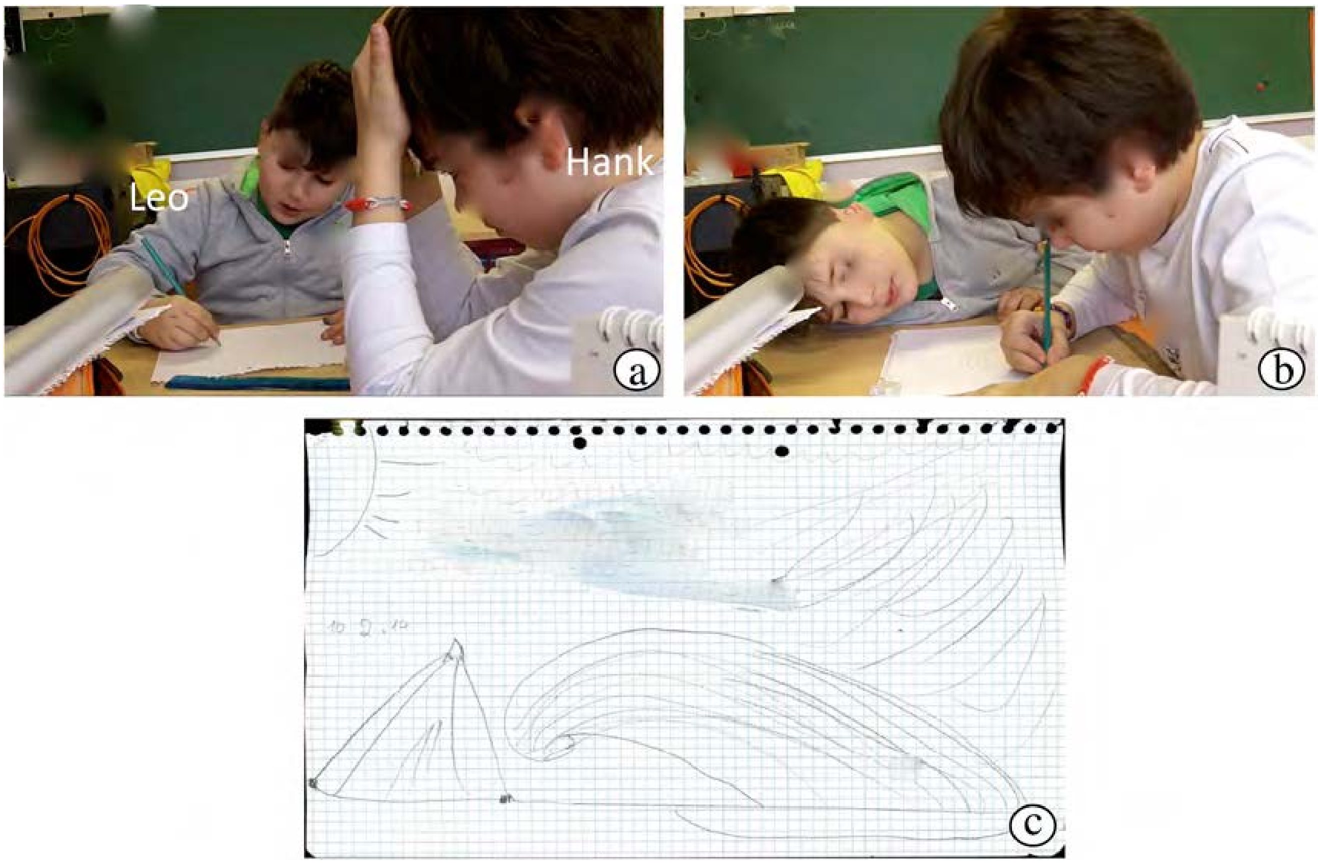


Figure 4.4. Leo (left) and Hank (right) passed the pencil back and forth to construct a notebook entry together (c).

Case 1, Excerpt 1[14]

Line	Speaker	Action	Spoken
01	Leo	Laying a new sheet down in front of him on the table	Okay ...predictions
02	Hank		What is that?
03	Leo		A wave
04		Reaches for the pencil. Then begins adding to the wave image	
05	Leo	Focusing on image, draws a tent	Leave a place for the tent.
06		Hank puts down pencil and Leo picks it up	
07	Leo		I will draw like this, and like that..a sun, a few clouds….

[14] Transcription conventions used throughout this chapter are as follows :

. . .	Periods indicate a pause in speech, one equals one tenth of a second
| |	Straight brackets contain overlapping speech
(( ))	Double closed parentheses depict action
xxx	Unintelligible vocalizations

Case 1, Focal Interaction B: Adding narrative to the representation.

Leo next took the notebook representation they created together and placed it directly on the table in front of him. He began to write narrative text at the top of the representation. As he wrote, he spoke each word out loud to himself in German (Table 4). He continued in this way, speaking each word out loud, almost sounding each word out as he spelled it, to produce an entire text (Figure 4.5, Excerpt 2, line 02). The information contained in the German narrative he wrote is parallel in content and processes to those depicted in the representation. This focal interaction, when considered as following Focal Interaction 1A, reveals that the notebook provided a space for the collective, collaborative production of a representation, as Leo and Hank exchanged in Luxembourgish, which as followed by an individual opportunity for Leo to write and speak the names of the items he wrote, in German (Figure 4.5).

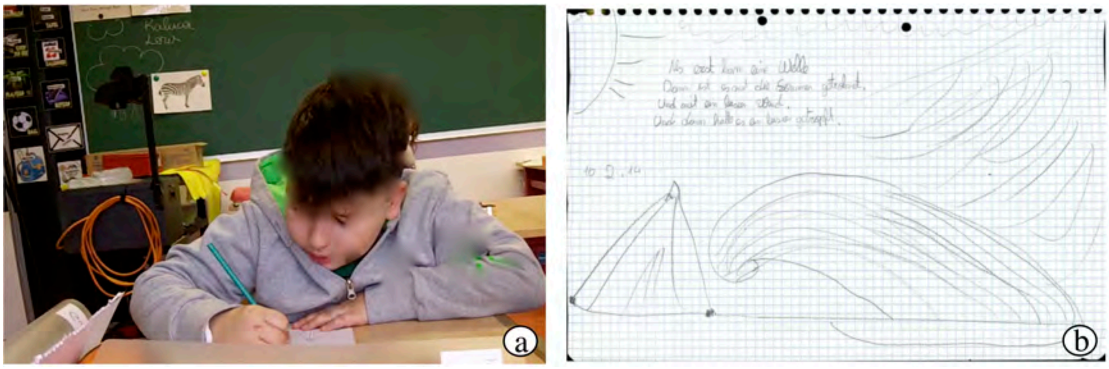


Figure 4.5. Leo wrote narrative (a) on the representation constructed with Hank (b).

Case 1, Excerpt 2

Line	Speaker	Action	Spoken
01	Leo	Writing in notebook Tapping pencil on desk while looking down at notebook	We have to write,
02	Leo	Writing in notebook	First a wave caaamme then the suuunnnn the sun dried then with a little wind, with a little wind theeennn it dripped

Case 1, Focal Interaction C: A second representation showing a different perspective. Next, Leo took a third piece of paper and placed it on the desk in front of him. He started a new drawing, this time drawing a perspective of the tent from inside (Figure 4.6). As he drew, he spoke aloud the name of each item he drew in the representation, using the German names of each items he is drew – bed, cloud (Excerpt 3, line 01). This mirrors the same technique he used when writing in Focal Interaction B, in that he spoke aloud each item one-by-one when writing about them in the narrative.

At the same time, Hank (Figure 4.6, off screen right) was told by the teacher to begin a drawing his ideas. Hank took out a piece of paper, and said, *I am going to draw another picture* (line 05) and began drawing five different tents, each numbered and occupying a different space on the notebook page. The dialogue that next occurred between them was a mixture of Leo describing what he was drawing and playful voices.

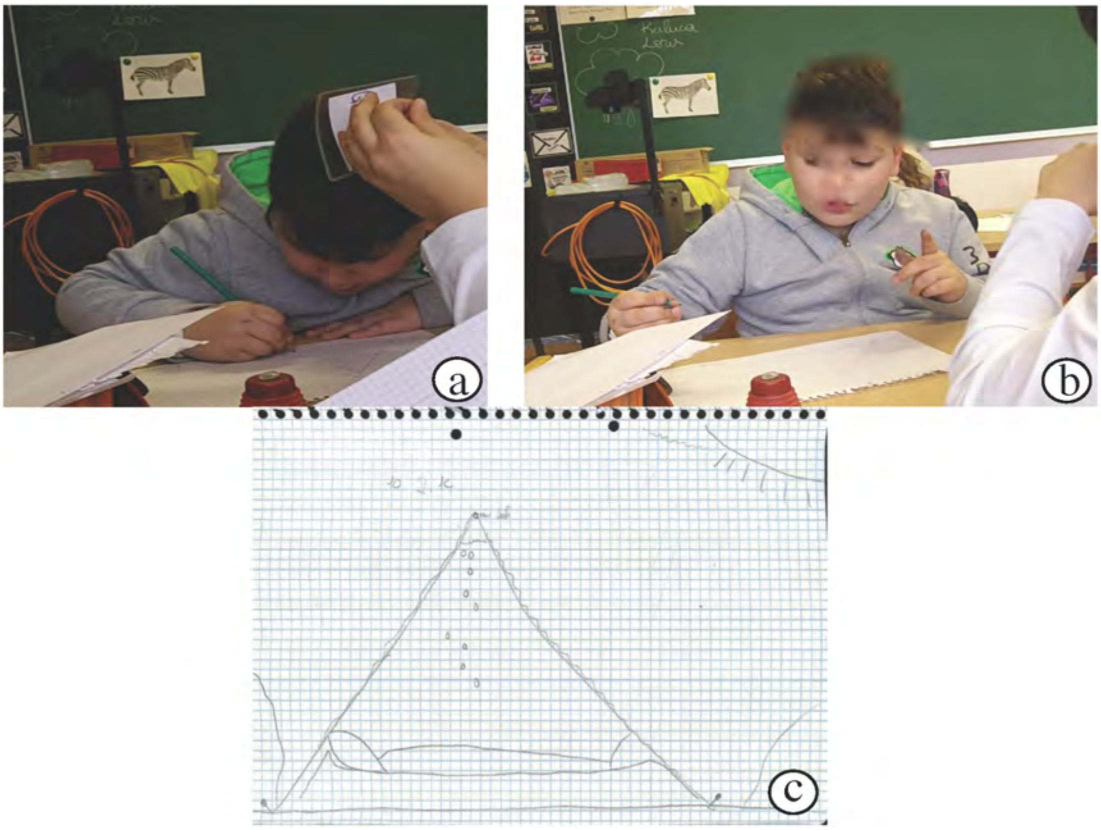


Figure 4.6. Leo (a,b) constructs an entry showing the inside the tent (c).

Case 1, Excerpt 3

Line	Speaker	Action	Spoken
01	Leo	Drawing the bed	A big bed Here another cloud So…..done
02	Leo	Pointing up, while speaking	Why?
03		Looks up, pushes finger on nose, looks at Hank	(playful voices)
04	Leo	Drawing at the top of the tent	Mini-hole, a mini-hole
05	Hank	Takes out a pencil	I am going to draw another picture

Case 1, Focal interaction 1D. Notebook conversation with the teacher. Chris approached the group and asked in German, *How is it going for you two?* (Excerpt 4, line 02). A conversation then took place between Chris and Leo. First he explained in detail what happened in the prior investigation (lines 03-08), as he pointed to the notebook entry. Then he turned the page to the representation he made with Hank (Figure 4.4). In this interaction, he referenced the three different notebook pages, each representing a different perspective. He explained that his investigation on Day 3 had not worked well, thus the frowning face. Next, he explained that a second attempt worked better, and this was why he drew a smiley face. Then he explained to the teacher the details of the investigation. Then he turns the page in his notebook and explains that he thinks that there is a little hole in the tent and that it could be that there was a wave that got water on the tent. His verbal explanation to the teacher parallels the content to in both his drawing and the narrative description he constructed in his notebook entries.

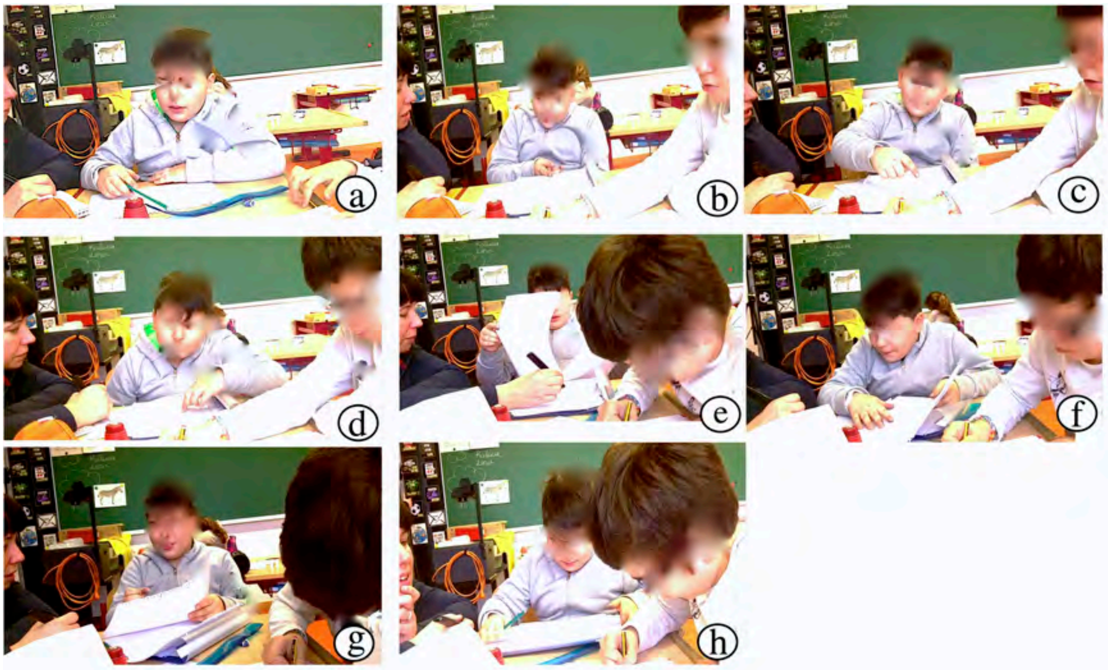


Figure 4.7. Leo talks to the teacher about his notebook entries.

Case 1, Excerpt 4

Line	Teacher	Leo	Hank
01	((Walks over to group and bends down to table where they work))	((Drawing in his notebook))	((Drawing in his notebook))
02	How is it going for you two?	Really good.	
03		((Turning to entry in Figure 4.3)) [Fig 4.7a] My best prediction now is ((Pointing to left side of entry)) [Fig 4.7b]	
	((Looking at Leo's notebook))	((Pointing to left side)) [Fig 4.7c] Here it might work, the magnifying glass is a little more back	
04	Why did you make a sad smiley face here?	Because it didn't go so well ((shaking head))	
05	((Points to paper))[Fig. 4.7e] This is your new plan? How do you tell the difference between the two plans?	Leafing to a different notebook entry	
06		((Pointing to notebook)) [Fig 4.3 left] Um..here it didn't work. Here it can work because the magnifying glass is a bit more away, and we added water	
07	((Pointing to part of entry)) And is this paper?	No, tinfoil	

08	Tinfoil, okay. ((Records in field notes))	((Flips page))
09		And here we both drew ((Placing entry Fig.4.4 in front of him))[Fig. 4.7f]
10		And here I wrote [Fig. 4.7g]
11	Okay	

Chris next turned to Hank and asked if he had the same idea (Excerpt 5, line 01). He replied*, I have something a bit different. I am trying to make five ideas* (line 02), while focusing on drawing the five representations in the notebook on the table in front of him (Figure 4.8). Chris responded, *Five ideas, okay, and how are the ideas different?* (line 03), to which he replied, *I don't know yet,* while keeping his gaze set down on his drawing in his notebook, all the while still constructing images. His conversation with the teacher conveyed that he had multiple ideas. The notebook was as a space that allowed him to document the multiplicity of his ideas.

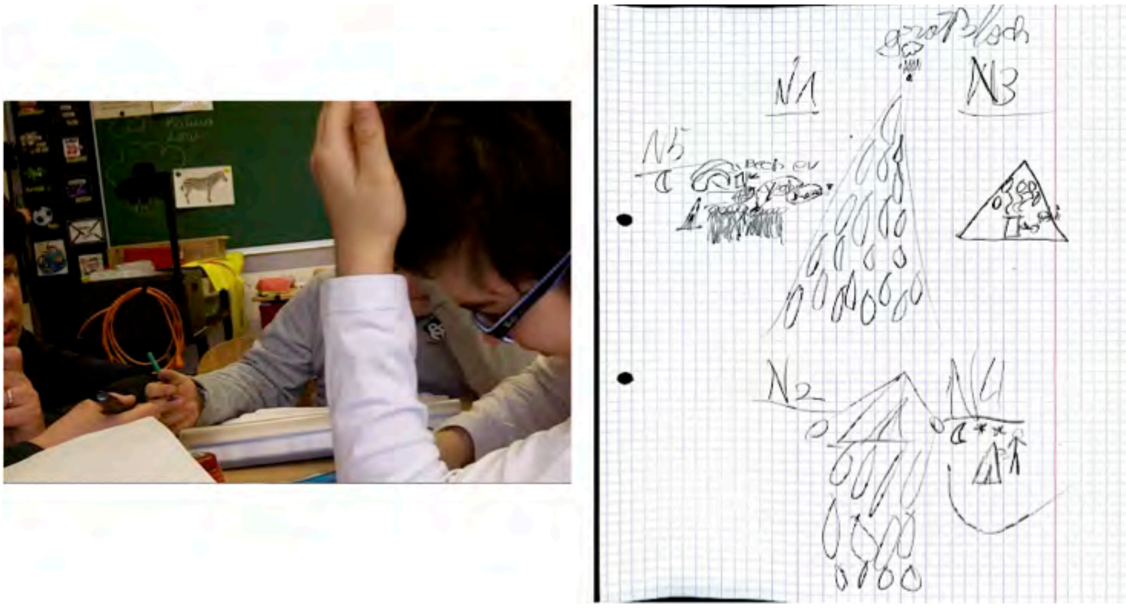


Figure 4.8. Hank (left) drawing multiple ideas for the droplets in the tent (right)

Initially, Hank represented three images in his notebook during the individual task (Figure 4.3). During the time he worked with Leo, his ideas increased from three to five. While video analysis did not show him discussing this increase, or giving any verbal indication of this, he changed the number of representations he was considering across this period. He was not seen working directly with Leo.

Case 1, Excerpt 5

Line	Speaker	Action	Spoken
01	Teacher	Looking at Leo and Hank	Okay, you think the same thing Hank? You have the same idea?
02	Hank	Focused on the drawing representations in his notebook on the table in front of him	I have something a bit different I am trying to make five ideas
03	Teacher	Hank keeps drawing representations in notebook	Five ideas, okay, and how are the ideas different?
04	Hank	Continues drawing representations in notebook	I do not know yet
05			You don't know yet. Okay, I will write down, Hank has five ideas

As Leo constructed an entry in the time of Focal Interactions A through C, Hank appeared to be *off task* in an instructional sense. He was seen first manipulating his ruler, and then his nametag. He was not seen interacting with his own notebook until later. Yet, when directly asked, the number of representations he recorded in his notebook had increased.

Case 1, Focal interaction 1E: Constructing a new investigation plan. Leo next asked for more paper. He placed the paper on the table, and began drawing. At the same time Hank stood up and spoke to the teacher who was standing nearby (Figure 4.9). Leo continued, constructing a revised investigation plan (Figure 4.9). Then, Leo began a conversation first with Hank, and then was heard discussing types of waterproof fabrics with the teacher and with Hank.

Leo explains that he would like to conduct an investigation to try out tents with different types of materials. Leo then used the space of the notebook, and constructed an investigation plan (Figure 4.9 left) to construct a plan for an idea he wanted to try next. There was not a next investigation period planned. Regardless, he constructed his plan and spent the remainder of the work time discussing types of materials, and devising a materials list for things he would need, and drawing the investigation in his notebook.

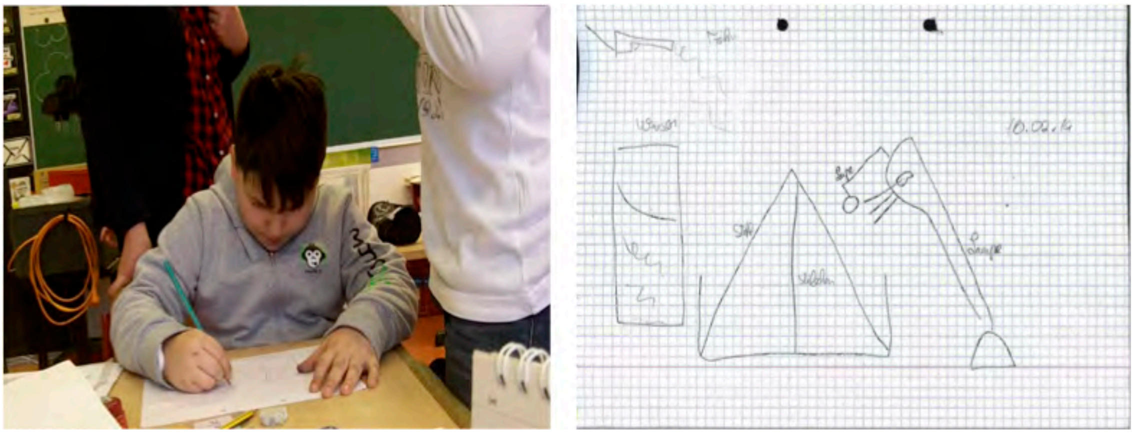


Figure 4.9. Leo (left) constructs a new investigation plan (right) while Hank stands and talks to the teacher

Overall, within this small group Hank and Leo choose different genres (investigation plan versus narrative and representation) to communicate their thinking within the same teacher-directed task. They moved back and forth fluidly in this space. They worked both individually and collectively to represent their understandings about condensation and the tent, and to discuss the construction of these representations. The space of the notebook was also flexible in that it allowed Hank to represent first three ideas, and then for this to increase to five ideas.

Case 2: Roberto and Marc

In the second case analysed, Marc and Roberto individually constructed notebook entries guided by the teacher-directed task prompt on Day 4. Marc wrote a narrative explaining that he thought the tent was wet and that they had left it in the washing machine (Figure 4.10).

Case 2, Focal interaction A: THE solution to the story. Roberto and Marc came together to work in a small group. Roberto opened his notebook to a new page and wrote *The solution to the story The Tent that Cried,* which was the title given on the handout on the first day explaining the text of the story. It was Roberto who decided they needed to construct a notebook entry that explained the solution to the science mystery. He initiated the construction of a notebook entry that reflected this goal. It is likely that Roberto transferred this title, which was also printed at the top of the handout, and used this to define the task space in his notebook.

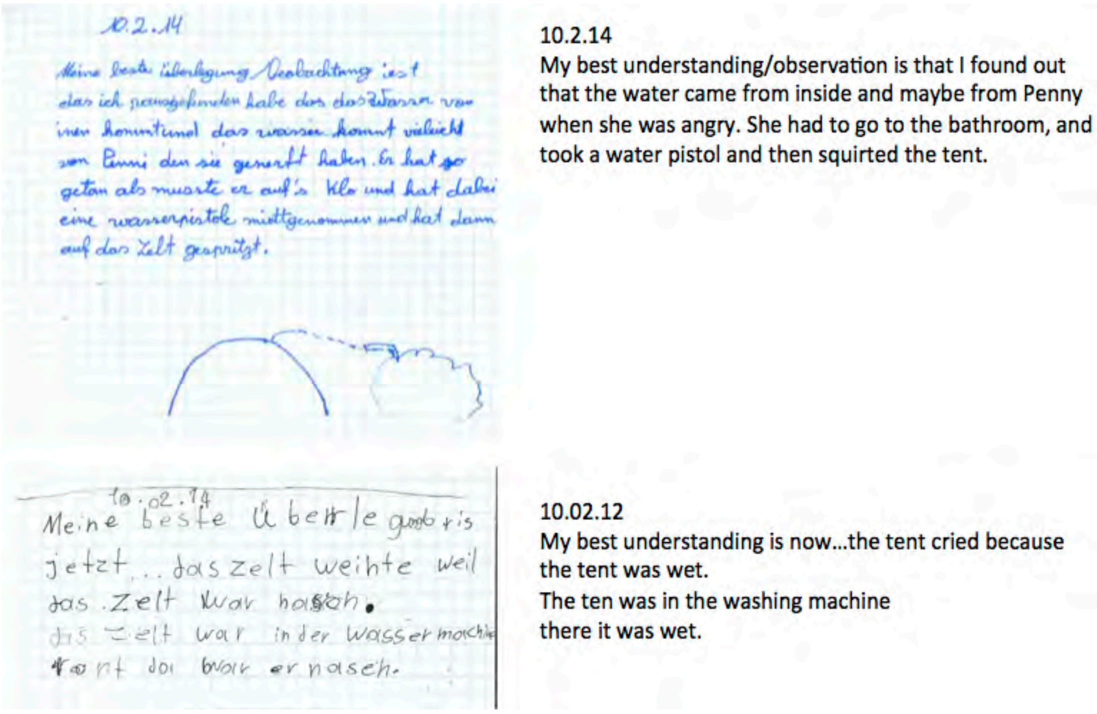


Figure 4.10. Roberto's (top) and Marc's (bottom) individual notebook entries explaining their ideas about the precipitation in the tent.

Instead of describing what he understood, which he did in the individual entry (Figure 2, left), in this interaction he begins to construct a *solution* to the story. Roberto was afforded the space to determine how this notebook entry construction proceeded and in ways that were different from what the teacher intended. Case 1 analysis showed the two students collectively constructed one of multiple representation to demonstrate their understanding. In comparison, in this group

Roberto constructed a narrative entry in German, and Marc constructed the exact same entry in his own notebook. Through my familiarity with Marc from our work together during the research study over a six-month period, I came to understand he was not very comfortable writing in German. He often used this strategy of duplicating his partner's work in his own workspace. Bligh (2013) refers to this strategy as *not just copying* as a way that language-learners structure their participation in tasks, they feel they would not be able to complete on their own. The majority of the dialogue that took place between Marc and Roberto while Marc constructed his entry identical to Roberto's, centred on clarifying spelling and inquiring about the German words used.

Figure 4.11. They work together (c) to construct Marc-s notebook entry (b), which is identical to Roberto's (a).

Case 2, Focal interaction B: Scientists discuss their ideas. Jana approached the group and encouraged them, in German, to share their ideas saying, *Did you speak to each other about your ideas? Scientists speak to share their ideas and exchange about them*. Roberto turned to Marc and in Luxembourgish asked, *The experiment from before, did you understand it?* Marc replied, *No* and flipped back through pages of his science notebook back to the photo he took during the prior investigation. *There*, Jana said as she pointed to the investigation photo and she asked, *what did you do there?* (Figure 4.12), pointing to the photo he had taken the prior session, and had in his notebook.

Figure 4.12. Marc discusses his investigation with the teacher.

Marc pointed to the same image in his notebook (Figure 4.12b) and replied in German, *My thinking is that that . . . I thought that*, *I thought that the tent was wet*. Jana then asked, *where did the water come from?* He shrugged (Figure 4.12c), as if to indicate he did not know, but then offered the idea from his explanation entry (Figure 4.10), *From a washing machine* (rising tone). Then he continued, *I think it came from a* *cloud ((*pointing up)) (Figure 4.12d). Jana built on this, *so it would have come from outside. You said before it must have come from inside.* Roberto entered the conversation adding that that based on the investigation he did last class, he found out that the water was coming from inside, not outside. This supported Marc's discussion with Jana. Roberto added, *From the body, the body,* and Marc supported repeating, *The body*. Both students then continued to build on this conversation with the teacher, *From the head, from the eyes* they said to the teacher quickly in German, while tracking her with their gaze, adding to their list of ideas. *It is best* Jana explained, *if you think about this and discuss this together* and then she walked away from the table leaving them to work on the task together.

In this interaction between the students, their ideas, and the teacher (Jana), the notebook was a source of ideas in that it prompted Marc to explain his thoughts about the washing machine. As enabled by the image of Marc's prior investigation, and through the conversation with the Jana, interaction unfolded that lead the students from their prior grounded experience in the investigation to an understanding that their ideas did not fit with what could be happening with the condensation. In this focal interaction they establish a key piece of understanding that the water was coming from inside the tent.

A few moments later Jana returned to the group and explained that scientists share ideas and speak to each other to clarify their experiments and their ideas. This is inline with views of science inquiry education that engage students to work in inquiry activity as scientists do (Rivera Maulucci et al., 2014). Jana then explained that Roberto and Marc had the opportunity now to share their ideas with one another. Roberto next said to Jana, *Ah, I know something! They showered*, and Jana encouraged, *Okay write it out* she says, to encourage him to record the ideas in his notebook. In interaction with the teacher, Roberto and Marc drew next upon their lived experiences from outside of class (Shepardson & Britsch, 2001) *water is produced by the body when you are sick and sweat* they exchanged verbally, with their notebooks sitting on the table in front of them. They did not interact with the notebooks at this point. Instead, they conversed in the space above them. *Maybe they were sweating because it was so warm*, Marc conjectured while crossing his arms. Jana came by the table and encouraged, *You can write this out*.

Figure 4.13 Marc and Roberto discuss the water coming from outside, maybe from sweating (right). They decide their written narrative is wrong, so Roberto crosses out the entry in this notebook (left).

However, they did not record their multiple ideas in their notebooks. They shared many ideas back and forth, but they positioned the notebook as the place where the single *right* answer is written. From this analytical perspective of the external view of the decisions and interactions surrounding their use of the semiotic social space, it becomes clear that they positioned the science notebook as a receptacle for transmission-based forms of science knowledge. This is aligned with Roth and van Eijck's (2011) explanation of canonical or views of science as a grand narrative, and that "not any answer, interpretation, or understanding counts but only the canonical" (p. 834). From the position that their idea they had written was not *the* solution, Roberto next crossed out the entry in his notebook, saying to Marc, *We can cross it out*, because he implied, it is after all not the correct answer (Figure 4.13). Even though Roberto and Marc were working within an inquiry-oriented unit, and were positioned within instructional and interaction spaces that allowed for the consideration of multiple ideas, they situated the use of the notebook as the receptacle of the correct information, or *the* answer. Multiple ideas were exchanged in interaction between them, and with the teacher (Jana) in the space surrounding the notebook, but no trace of this complex line of thinking and were recorded within the notebook itself.

Case 2, Focal interaction C: Our idea was false. Chris approached Roberto and Marc to conduct the small-group interview. She asked, *What did you find out*? (Excerpt 1, line 01) Roberto replied, “We did not find anything out yet” (line 02). This is ironic in light of what was revealed in analysis presented of Moments 2A through C, in that Roberto and Marc had just discussed multiple ideas, and had determined a key piece of understanding, that the droplets formed because of water vapour present inside of the tent. While Jana was aware of their multiple ideas, because she interacted with them in the course of their discussions, Chris was not. Here we see that Roberto told the teacher they had not found anything out yet. Chris probed further and asked, *What did you write down?* (line 03) *I had an idea,* Roberto explained, and after a bit more probing Roberto ended his conversation with Chris stating, *..but it was false* (line 08), a position which was further supported by the crossed out notebook entry.

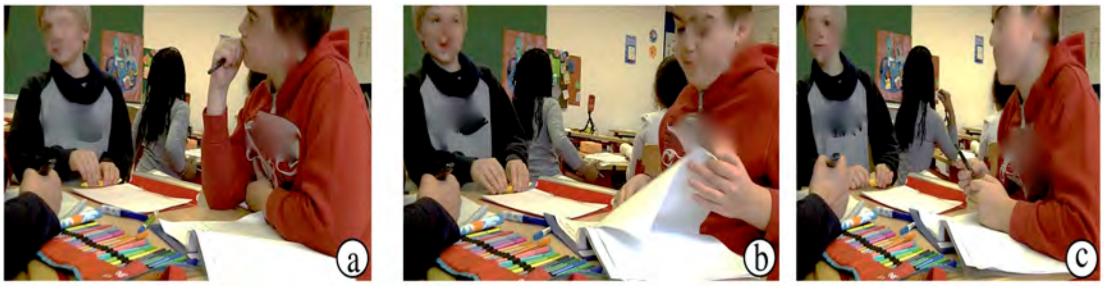


Figure 4.14 Roberto and Marc discuss their wrong idea with the teacher.

Case 2, Excerpt 1

Line	Teacher	Roberto	Marc
01	((Bending down by the group's table))		((Looking at teacher, then at Roberto as they talk))
02	What did you find out?	((Looking at teacher)) We didn't find anything out yet [Fig 4.14a]	
03	What did you write down?	I had an idea but it was a little bit too stupid	Mine was too
04	What do you think you found out? ((Looking at Roberto and Marc))		
05		We have something ((looking at teacher)) but it was false. [4.14b]	((Flipping forward and backward in notebook. then rejoining gaze to follow Roberto and Teacher))
06	How so? Why?	We invented a story.	
07	So, you wrote a new story?	Noooooo. I wrote out the answer to the story, but it was false.	
08	What did you write down?	We asked the other teacher, but it was false…and that it (the water) went up and then dripped down…but that is false. [Fig. 4.14c]	

Roberto and Marc drew on ideas revealed in past science investigations, notebook entries, and experiences from outside of class as they discussed their ideas and collectively negotiated multiple possible explanations for the condensation in the tent. This interaction occurred in the space surrounding the notebook, but was not documented in the notebook entries themselves. Even when this multiplicity of ideas was revealed to Jana in discussion, it was not later revealed to Chris as she conducted the interview. This is interesting in that in conversation with Chris (Figure 4.14, Excerpt 1), Marc was seen looking at past entries in his notebook (Figure 4.14b) but still they explain that their idea was false. Thus, from Chris' perspective it appears they had one idea, found it to be false, and thus stopped there with their thinking, when in reality they were generating multiple ideas, as became clear in their conversations with Jana. Their conversation with Chris in Focal Interaction C does not reveal the complexity of ideas they worked through together.

Case 3: Nia, Amy, and Calia

Nia, Amy and Calia individually constructed notebook entries in German as guided by the teacher-directed task that started Day 4. (Figure 4.15). They joined one another in a small group with instructions to discuss their ideas so far about the condensation in the tent.

Figure 4.15.Nia (a), Calia (b), and Amy's (c) individual notebook entries.

Case 3, Focal Interaction A: Animated transduction of modes. Calia began to read her notebook entry to the group (Figure 4.16). She read, word by word, in German. Two thirds of the way through, she stopped, looked up at Nia (Figure 4.16c), put down her notebook, and began using animated gestures to explain to Nia her thoughts about the tent. This shift from reading in German to speaking in Luxembourgish was accompanied by shifts in posture and gaze, as shown in the video offprints in Figure 4.16. When Calia shifted her focus, from reading from the notebook in German, to speaking and gesturing in Luxembourg, the notebook was backgrounded and no longer served as a focal point of the interaction. Her gestures became more elaborate, as if the science ideas became enacted in the space between her and Nia and Calia. This same pattern of shifting from reading in German, focusing on the notebook, then speaking in Luxembourgish, occurred moments later when Nia next explained her thinking about the condensation.

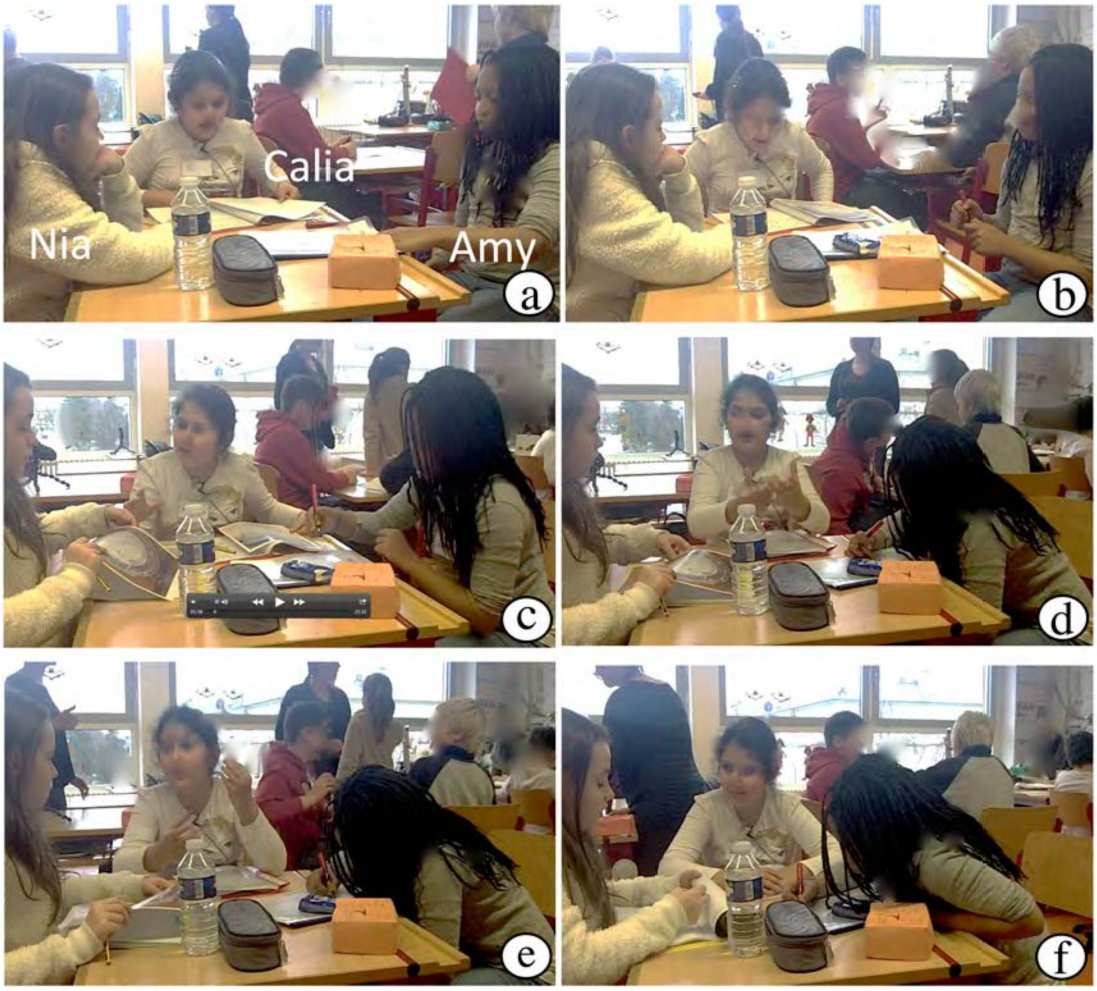
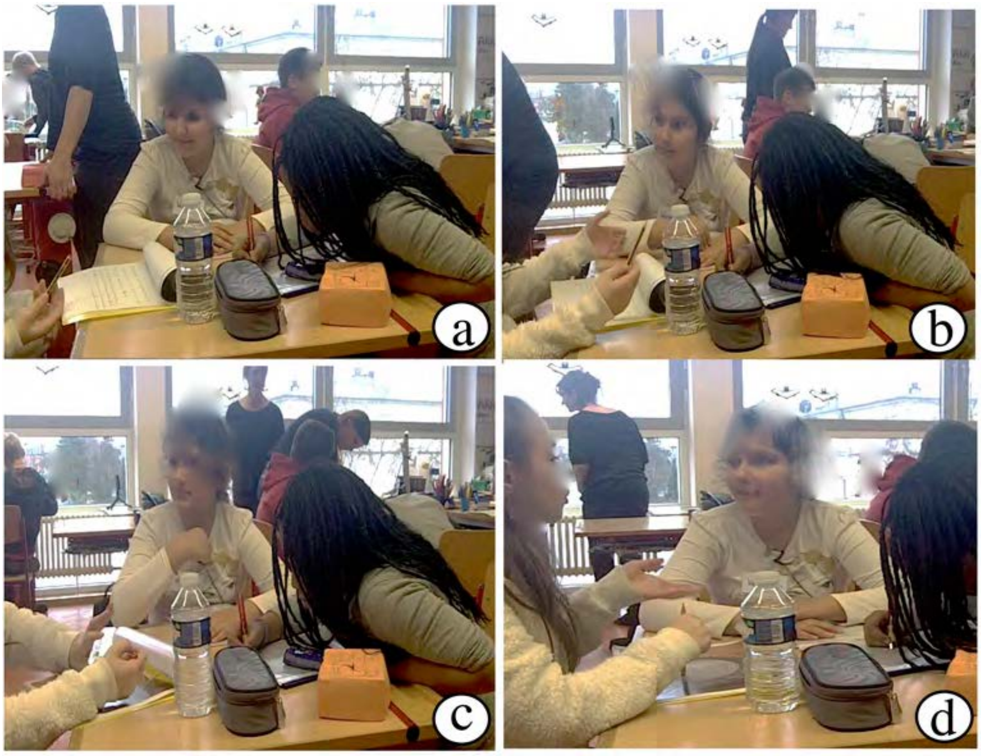


Figure 4.16 Calia transitioned focusing on her notebook and reading in German, to speaking with Nia in Luxembourgish.

Next, Nia read from her notebook (Figure 4.17a). After reading a few lines in German, she placed her notebook down on the table, and began speaking and gesturing, shifting her gaze to Calia (Figure 4.17b). As she spoke, she flipped back in her notebook, as Marc did in Case 2 and Leo did Case 1 to the photo of her science investigation from the prior session. She explained, *Do you see these drops*? and pointed with her pen to the photo in her notebook (Figure 4.17c), *They formed when we put the light over the set up (*on Day 3).



Figures 4.17. Nia transitions from reading (a) to speaking and gesturing (b,c,d).

For both Calia and Nia, their ideas and photo documentation of science investigations recorded in the notebook became resources in their current interaction. Both Nia and Calia drew upon the affordances of the notebook, and the interactional space, to transfer their ideas from one language into another, and from one mode (written) into another (spoken, gestural). As such, the notebook supported them in moving between modes in a process of *transduction* from written to spoken (Kress, 1997; Newfield, 2014). In this shifting from written, to spoken and gestural explaining, Mavers explains, “The move from one mode to the other has profound implications for meaning because of changes to what it is possible to mean” (MODE webpage, 2012). Calia and Nia were able to include resources (gestural, photos from prior investigations) in their explanations when speaking that they had not referred to or included in the German narratives written in their notebook entries.

Case 3, Focal interaction 3. Discussing ideas with the teacher. In the next focal interaction, Chris approached the group and asked Amy to explain her thinking. At that point, this group had not drawn representations of their understandings. They only had written narratives. The conversation unfolded as shown in Excerpt 1, below, and in Figure 4.18.

In this interaction Amy used a combination of gestures, both indexical and dietic (Goldin-Meadow, 2003) to explain her thinking to Chris. Amy utilized a strategy common to language-learners as she used gestures in her explanation to indicate what she is thinking about the phenomena. “Telling, as gesturing, gestates, or makes world” (Roth and Lawless, 2002, p.20). Amy’s use of non-specific pronouns (e.g., *this*) in the place of proper nouns to refer to specific phenomena, and the use of gestures to pantomime structures from her science investigation, can, as Roth and Lawless (2002) explain, arise in talk following a student’s manipulation during scientific investigations.

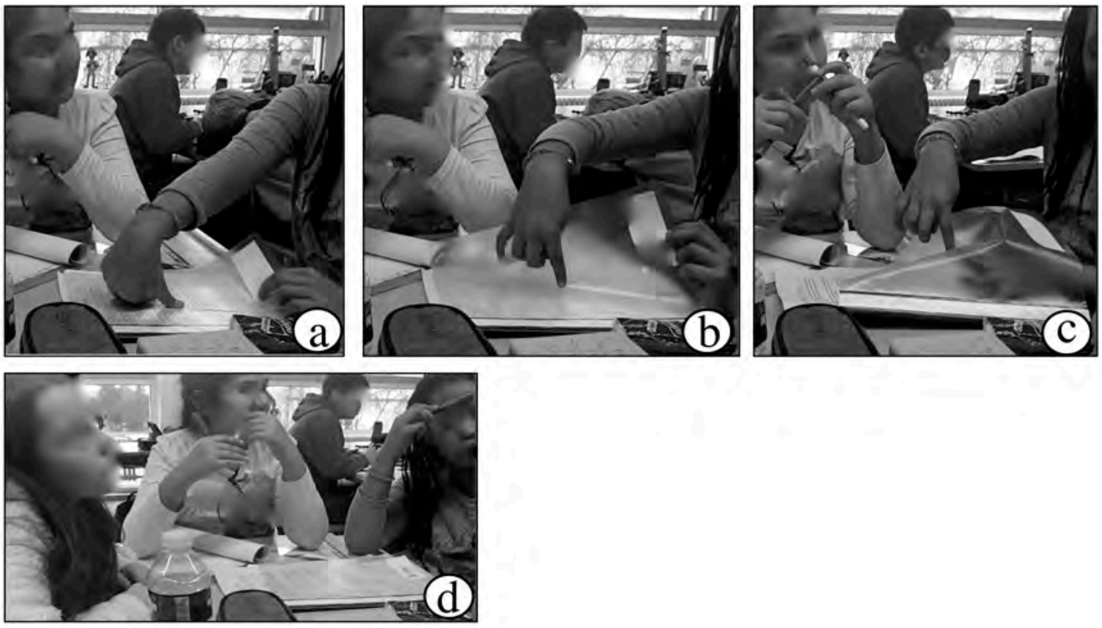


Figure 14.18. Amy discusses her understanding with Chris.

Case 3, Excerpt 1

Line	Speaker	Action and spoken
01	Amy	and so because maybe...there was a little, how should I explain this...a little so, a little ehhh,
02	Calia	A little warm
03	Amy	No, no, no. Ah a little, ahhh...for example when you xxxx put water onto it, ((thumb pressed in middle)) [Figure 3f] then ((pointed finger)) [Figure 3g] it goes like this ((pressing in the cover between her fingers to make a furrow)) [Figure 3h]
04	Amy	maybe this and then it went into the left eye and onto the forehead ((image point to forehead)) [Figure 3i] and into the right eye, that is my opinion..and she may have ahh....((wiggling in chair)) moved the whole time...and then it went first into the left eye then the forehead and then into the right.

Following this, Chris instructed Nia, Amy, and Calia to draw representations of their current understanding in their notebook. It is interesting to note that they all construct a similar image (Figure 4.18). One apparent difference is that Nia includes structures from the science investigations (lamp), while Amy and Calia include the characters from the story.

Figure 4.19 Nia, Calia, and Amy added drawings to their notebook entries.

Case 3, *Focal interaction 4: Discussing their drawing with Sara*. After Nia, Amy, and Calia drew representations in their notebooks, I came to the group to and I bent down to see at they had drawn. I had a conversation with the group as is represented in Excerpt 2 on the next page.

Figure 4.20. Amy (offscreen, right) and I discuss her representation in her notebook

Case 3, Excerpt 2

Line	Sara	Amy
01	Where did the water come from? ((pointing at the tent representation in Calia's notebook)) [Fig. 4.20, left]	
02		It was warm
03		The water went up ((motioning up on the tent representation)) [Fig. 4.20, middle]
04		Then it came back down ((tracing down the drawing of the inside the tent with her finger)) [Fig. 4.20, right]

As shown in the video offprints, throughout this conversation, Amy and I both pointed directly to the representation on Amy's notebook page (Figure 4.20). This is significant in that the notebook entry (shown in Figure 4.19, bottom), in Amy's notebook, prompted me to draw on this question and ask the group, *Where did the water come from*? (line 01). The notebook documented Amy's question, and I was able to see it represented on the page, and use it in conversation with the group. The conversation that followed was rooted in the notebook, as we both pointed to the representation as we spoke (Figure 4.19). The notebook was a site for mutual focus (Streeck, Goodwin & LeBaron, 2011), with implications for accessing student thinking regarding the process of science inquiry. If the notebook had not been present in the interaction, the teacher would only have had access to Amy's questions through dialogue, which did not materialize. Thus, the notebook provided an additional avenue to access her thinking and questioning.

Next, I extended the conversation, as I pointed back to the representation in Amy's notebook and begin the conversation elaborated in Excerpt 3.

Figure 4.21. Calia, Amy, Nia and I discuss tent shapes.

This was again an opportunity, through interaction with the students in the semiotic social space in and above the notebook, that I could access what was represented, and subsequently use this as a resource to further extend my discussion with the students' as I stated, *Maybe the tent was not like this ((motioning a tent shape))* (Table 4.11, line 03), and began a conversation in which all three group members contributed conceptualizations of possible tent shapes. This is a second example of the notebook serving as a resource for further semiotic meaning making in ways that become embodied in interaction and in ways that extended the students' thinking about the inquiry at hand. The notebook was a resource in that it afforded students a place to document their understanding, that then in turn, became a resource for further communication.

Case 3, Excerpt 3

Line	Teacher 3	Calia	Amy	Nia
01	This is really interesting that it dripped here ((pointing to entry in front of Amy in Amy's notebook)) and not here ((pointing to different spot on notebook)) [Fig. 4.21a]			
02		Because it was on this side ((pointing in Amy's notebook)) and not on this side ((pointing to different part of image)) [Fig. 4.21b]		
03	Maybe the tent was not like this ((pointing to point at top of tent drawing)) [Fig. 4.21c] Maybe it was like this ((makes flat bridge with hands)) [Fig. 4.21d]	((makes same flat shape with hands))		
04		Or like this ((makes angled shape with hands)) [Fig. 4.21e]		
05 06 07			Or like this ((makes more angled shape with hands)) [Fig. 4.22f]	Or like this ((makes wavy shape with hands)) [off screen]

In this case we see through the use of the notebook, that sequences of semiotic resource use flow from science investigation, to notebook, to teacher, to students, to notebook, to students, in ways that afford spaces to discuss, add and extend ideas, and draw from the multiple experiences in the science inquiry.

Cross-case Comparison

Trajectories showing the use of the notebook space (the entries students constructed) over time for the three cases are presented in Figure 4.22. It is useful to position the notebooks in trajectories in this way to compare notebook usage among cases. However, it was difficult to illustrate the trajectories in a manner that would enable clear reading of the notebook entries due to page size constraints. Entries that are easier to decipher can be found in prior sections.

In comparing the three cases a number of factors become apparent. First, each case shows that student group utilized the notebook space, and the affordances it offered in different ways. From an internal view of what and how students recorded in the notebook, each group used different framing mechanisms (number of pages, ways of representing, etc.). In Case 1 (refer to overview in Figure 4.22), Hank represented multiple ideas over a short period of time on one page. Leo utilized each page as a single frame for a different perspective (one page inside the tent, one page outside view of the tent). In comparison, in Case 3, Amy, Nia, and Calia had almost identical entries. Thus, the notebook provided spaces for flexible representation of diverse ideas through both narrative and drawn representations.

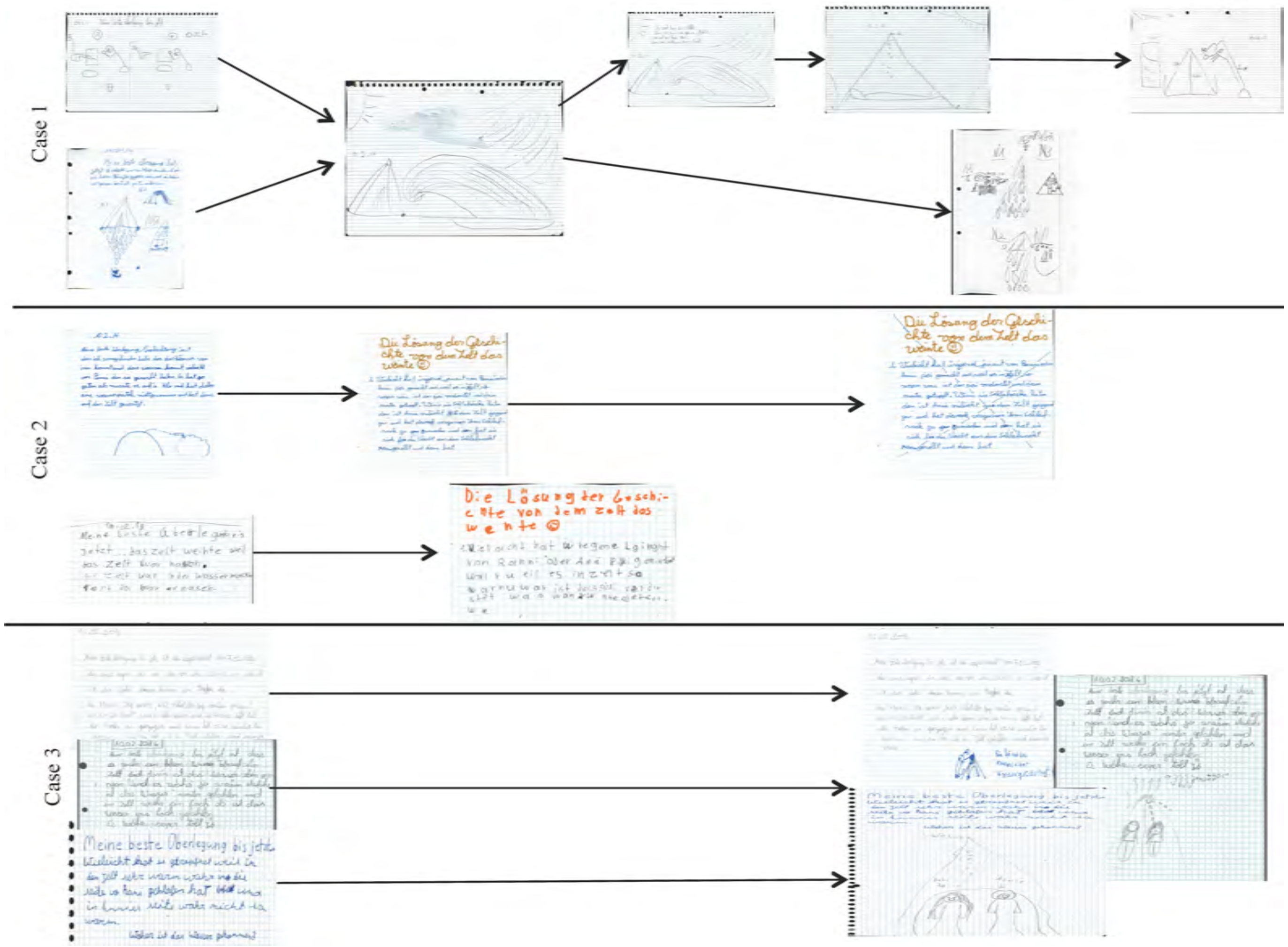


Figure 4.22 Notebook trajectories for 3 cases

Case 1 shows how students' ideas were multiple and changing over time. Students recorded different perspectives of the same situation, depicting different levels of understanding. This was not so in all cases. In Case 2, the notebook was a place where *the* answer was to be recorded. Thus, each group had a different orientation toward their use of the notebook. Overall, the notebook supported the use of flexible individual and collective spaces. This was seen in Case 1 where the two students moved from working on the same entry to working on quite different individual entries versus what was revealed in Cases 2 and 3 where quite similar entries were constructed. Each group was able to decide the use of the notebook semiotic space and the interactions that occurred around it, with each other, and with teachers, in different ways.

In all three cases, interactional views revealed students referenced multiple entries in the notebook in a single focal interaction. In Case 1, Leo does this when speaking with the teacher. In Case 3, Nia does this when explaining to Amy about the result of the lamp in their Day 3 investigation. This access to multiple forms of information through the notebook entries from different days reveals how students' thinking while constructing and working on Day 4 was informed by their prior work in prior lessons (Days 2 and 3) in the unit. Thus the notebook supported connections through time between the entries that, more accurately reflect the multi-faceted understandings they developed as they weaved together their investigation experiences in class, with their lived experiences. These connections would not have been apparent if the notebook entries from Day 4 were analysed as texts in a single moment.

Discussion

Interactional views of student science notebook use

This study set out to examine semiotic social spaces in and through science notebook use in a multilingual classroom. It approached the research questions, how do students use the notebook space in the context of an inquiry-oriented science unit? What is revealed when this is viewed through the lens of multimodal interaction analysis? Analysis of both internal (notebook entries) and external views (interactions surrounding construction of entries on Day 4) of students' semiotic resource use both within and around the notebook, revealed the pedagogical potential for science notebooks with regards to engagement in practices of science, and in interaction with peers and teachers. Specifically, the analysis presented herein revealed that students drew on multiple resources – the investigated, the lived, and the imaginary and their ideas shifted over time. It was also shown that the use of representations to document understandings in notebook entries could be contingent, and represent multiplicity. This supports the analytical approach put forth by Tang et al. (2014), in underscoring the importance of viewing students' multimodal representations, such as those recorded in notebooks in this study, across time scales that are greater than one lesson or one task. Additionally, analysis revealed that students had engaged complex reasoning about their understanding on Day 4 that was not always reflected in their notebook entries.

Science practices as individual and collective work

Once the students began working in small-groups, each case followed a different path of individual/collective work in what they produce. Each of the three cases shows students chose different ways working together, and ultimately a different trajectory. Thus, the structure of the notebook space, coupled with the inquiry-based unit and the teachers' approach to notebook use afforded students the space to assume a multiplicity of orientations toward their group work.

This builds on prior analysis conducted within the same overarching study that examined how the participatory instructional approaches in this science unit supported students' agency to determine their role in the inquiry science activities (Siry, Wilmes & Haus, 2016). In the research I present here, I build from our prior work, and extend it by showing how the notebook afforded students, within the instructional structures, the space to decide how used the notebooks.

Prior research has examined students' science notebooks in order to examine the science content and process that students understand in multilingual classrooms (see for example Zhang, 2016). In this study, I champion a wider interactional-based view of science notebooks, one that examines the type of science practices students are positioned to engage in when working with the science notebook in the semiotic social space of an inquiry-based science classroom. This builds from prior studies such as Weibe et al. (2009) who sought to identify which science processes are revealed in students' notebook documentation. The study I present here extends this prior research in a novel application of multimodal interaction analysis to shift views of science notebook use from those that view notebook entries as static texts. The goal of this was to thus attempt to discern the science processes involved in entry construction. I sought to adopt interaction views that more clearly portray the interactions, discussions, and moves that surround the use of the notebooks and that provides views of students' notebooks not as *frozen modes* (Norris, 2004) but as a tool that can afford interactions that support science as inquiry and science-in-interaction (Siry, Ziegler & Max, 2012). Two interactive views arise in particular, from the analysis presented herein, views of students' science practices in action, and views of students' linguistic resource use in action

Viewing science practices in action

Viewing science notebook entries in interaction provided insight into the minute-by-minute negotiations that went into their construction, and the interaction that occur in the spaces surrounding the notebooks. Thus, this analysis provided insight into why one entry is crossed out (Case 2, it was not the right answer), and reveals students positions regarding the nature of science (the notebook was only for recording the final answers, revealing students' deterministic views of science). In interaction, we saw how students moved back and forth through the notebook entries (Case 2, in speaking with the teacher; Case 3, in speaking with the small-group) as they discussed their understandings, drawing on photos taken in previous lessons during investigative class experiences. Thus, interactive views of notebook use provide a view of science that is active and unfolds in interaction through time. I refer to this process as sciencing, in that science is viewed as a process in which students engage. Interactive views of the notebook use over time show us how students entertained multiple ideas (Case 1 and Case 2), but only when positioned to view the notebook as a flexible space, did they record multiple ideas (Case 1). This is significant because the pedagogical potential of this active view of science places increased emphasis on the need to support students in their interactions with and around the notebook, and with each other when using the notebook. It also supports the teachers' framing of the notebook in ways that enable students to view it as a place for documenting many ideas that unfold in space and time, and to view their ideas as contingent. It reveals that the use of science notebooks has the potential to support students' development of the epistemic practices of science, not just science-as-content and process skills. The nature of science is dynamic and unfolds in interaction with the notebook, peers and with teachers.

Additionally, the analysis presented here shows how transduction (Kress et al., 2001), that is, translation from one mode into another, occurs multiple times over the trajectory of a unit of science inquiry, and across the space of a small-group activity. We saw how the students transformed resources between modes as a way of realizing meaning (Kress, 2000). In past work on science representations, researchers have focused more solely on single chains of semiotic resource use, for example from the teacher to the student. For example, Kress et al. (2001) explain “one of the functions of action in the science classroom is to provide the raw materials for the production of texts.” (p. 27). This study builds from this view and extends this into movement through multiple chains of semiotic resource use in interaction, from the teacher, to the students, to investigations, to notebooks, and back again. Thus the views of semiotic resource use presented here are social, dynamic, complex and do not follow a single, linear trajectories from teacher to student, and then into the notebook. In fact, the analysis presented raises several question regarding multimodal methodologies that seek to establish direct, linear links between a teachers’ semiotic resources use, and subsequently a students’ use as a result of instruction.

Viewing communication resource use in action

In this study multimodal interactional analytical lenses, provided views of the students moving from one mode (written) to another (spoken) from one language (Luxembourgish) to another (German), and back and forth. These views reveal fluid processes that unfold in interaction. The notebook supports this fluid movement from one setting (writing individually in German) to another (speaking and gesturing while working in small-groups in Luxembourgish). Thus, the notebook is a tool that supports this fluid movement back and forth as students engage in sciencing, and actively moving through dynamic use of linguistic resources.

The approach used in this study reveals semiotic resource use in action. Thus languaging is visualized. In the analysis presented in this study, we see rich, fluid use of multiple languages and multiple modes over time. This confirms research that shows that languaging, and associated forms of accessing multiple languages and semiotic resource use in the context of learning, such as translanguaging (García, 2009), is beneficial for students' meaning making.

In conclusion, viewing the notebooks as semiotic social spaces and adopting analytical tools to examine both internal (content) and external (interactions and decisions about the content) affords us views of not just what is in each notebook entry and the trajectory of such in time, but also of the social interactions, decisions, and moves that go into fluid semiotic resources use in action (Gee, 2005).

The pedagogical potential of science notebooks

The analysis presented herein reveals the pedagogical potential of science notebooks. For example, analysis revealed there were missed opportunities for the teacher to see what had been revealed in students' discussion, but that was not recorded in their notebooks. This is an opportunity to underscore that there can be different epistemological stances relative to the use of the notebook. If teachers are aware of this, they can seek to dialogue with students around their entries to explore students' decisions about what they construct in their notebook representations.

Analysis of the notebooks and their use in this multilingual classroom from both internal and external perspectives reveals that the pedagogical potential exists for supporting sciencing and languaging, and the creating of spaces where students can engage in processes of representing multiple modes, and negotiating their use in interaction, over the course of an inquiry-oriented science unit. When used in animated ways, opportunities are created for our students to have more voice in the process of learning science, rather than static views, which reduce representation to frozen moments detached from the fluid intersemiotic moments from which they were created.

In this study, teachers were positioned to enter into dialogue with students regarding their representations. At times this revealed complex understandings (Case 1 and Case 3) that were reflective of the multiple understandings students held of the inquiry. In other moments, interactions with the teachers discussing over the notebooks failed to reveal complex students understandings (Case 1 and Case 2). Analysis herein shows that this was not because of students' understanding of the science processes, or due to their non-participation in inquiry, but instead due to the static view of the notebook in that one point in time. Thus, there is potential here to extend the use of the notebook, to revisit the notebook several times in instruction, in order to truly see the complex, detailed understandings students had negotiated over time and in interaction with their groups.

Implications

There are several implications from this study for future research on semiotic resource use in science classrooms in general, and the role of science notebooks in these processes in particular. The analysis in this paper reveals the pedagogical potential of science notebooks, and how when viewed in animated semiotic social spaces in time, how science learning and semiotic resource use move from being static, into action. The recording of representations in a science notebook, when animated through interaction with self over time, with peers, and with teachers transforms science into sciencing, an active process that more closely resembles the emergent, in interaction processes undertaken by scientists, and that has the potential to teach students the epistemic practices of science, not just content and process skills.

Thus, pedagogical potential exists through the use of the notebook to foster fluid interactions, sciencing, and languaging, resource use that was only partially realized in some of the cases presented. Methodologically and pedagogically, this research expands views that conceptualize students' representations in the context of science notebooks, as static texts (Chandler, 2007). This analysis has shown that in a classroom engaged in inquiry instruction, multimodal interaction analysis of science notebook use reveals active semiotic resource use in interaction that are not revealed through static analytical lenses. Thus, this analytical approach reveals richer views of students' resource use as they engage in science, and highlights areas for improving the pedagogical value of science notebooks use in science instruction.

CHAPTER 5

INTEGRATED DISCUSSION

This dissertation is an interpretive qualitative study of the use of an inquiry-based student-driven science instructional approach in trilingual primary schools in Luxembourg. Three analyses rooted in sociocultural theories of science learning were presented in the preceding chapters, each providing a different lens on the implementation of this instructional approach. In this chapter, I bring the dissertation to a close through an integrated discussion of the crosscutting understandings that arose from the integration of the multiple analyses. The sections that follow will further highlight the novelty of the study, and elaborate how the analyses presented contribute to research on the use of inquiry-based programs in multilingual settings in general, and in Luxembourg primary schools in particular. The chapter concludes with a discussion of the implications of this study for teaching, research, and theory, and provides suggestions for further research.

Summary of the Study

Grounded in sociocultural theoretical perspectives, this study examined the implementation of Science Workshop, an IBSE student-driven science instructional program developed to address science education needs in Luxembourg public primary schools. The research study, and the student-driven IBSE it analysed, arose from an identified, contextual need for science instruction that is responsive to an increasing linguistically and socioeconomically diverse student population, coupled with limited science instructional time within the language-dominated curriculum, the goals of the IBSE approach studied were two-fold. A first goal, as also elaborated in Chapter 1, was to use students' questions as a driver of science inquiry, and a second goal was to position students to interact in dialogic ways within science education.

The results presented in Chapters 2, 3, and 4 were drawn from an expansive data corpus collected across a year and a half timespan in which Science Workshop was piloted, field-tested, and also implemented in teacher professional development workshops. I employed ethnographic research methods, grounded in sociocultural theories of science learning and language use (e.g., Lave & Wegner, 1991; Lemke, 2001; Wertsch, 1994) to analyse instructional opportunities at multiple levels. Several related methodologies, specifically case study analysis, interaction ritual analysis, and multimodal interaction analysis, were used, which afforded views of voices (students', teachers', researchers') and heteroglossia across various aspects of the study. When considered together, the multiple layers of analysis I present in this dissertation provide complementary perspectives through which to view the use of the inquiry-based instructional approach in primary schools in Luxembourg. Thus, this study contributes to the existing literature base on the use of inquiry-based instructional approaches in multilingual contexts in general, and elaborates findings and specifics relative to use in Luxembourg in particular.

To reiterate, the overarching research questions that guided this research were:

i. What types of instructional opportunities does Science Workshop, an inquiry-based student-driven science instructional approach, afford when used in Luxembourg primary classrooms?
ii. What does analysis of interactions in these contexts reveal about inquiry-based science instruction (IBSE) in multilingual classrooms?

The next sections summarize the findings and understandings that emerge from the study as a whole, and illuminate the themes that arise from their synthesis.

Synthesis of the Findings

Through a process of working with teachers over time, this study identified programmatic factors that supported teachers' use of this IBSE instructional approach. These factors included participation in professional development workshops over extended time periods, opportunities to engage in experiences of inquiry-based instruction themselves, adaptable instructional activities for classroom use, materials for science teaching, and coaching support during science instruction. These teacher-identified factors that supported their implementation of IBSE with their students aligns with findings from a wide base of research that elaborates the factors that assist teachers in implementing IBSE (e.g., Anderson, 2002; Loucks-Horsley et al., 2009; Stoddart, 2011). Drawing on this wide research base in the international literature in science education, this project was the first of its kind to offer *multiple cycles* of teacher professional development opportunities to support inquiry-based science as grounded in students' questions in Luxembourg. This builds from findings gleaned from past IBSE projects in Luxembourg, such as The Fibonacci Project, which identified a need for locally relevant approaches to IBSE for teachers as well as students, to develop an approach designed specifically to facilitate student-driven inquiry in Luxembourg primary schools.

To summarize what has been elaborate in Chapters 2 through 4, the analyses of the instructional opportunities afforded through the use of Science Work revealed that students were positioned to actively select the languages in which they worked, thus creating heteroglossic learning spaces within the monoglossic instructional space (Chapter 2). Additionally, the use of ritual components in IBSE instruction (small-group student-driven investigations, science notebooks) afforded students spaces to create interaction rituals on micro-scales that supported their dialogic participation in science investigations (Chapter 3). Lastly, multimodal interaction analysis of science notebook use in a focal class demonstrated that the use of the notebooks mediated students' flexible use of semiotic social spaces in interaction (Chapter 4). As an overall summary, the analyses revealed that *spaces* were created that allowed for recognizing and affording heteroglossic processes and practices. These were spaces for asking and investigating questions, engaging in a diversity of interactions around science explorations, and utilizing science notebooks within the inquiry-based context of instruction. The understandings gleaned from considering this study as a whole can be summarised as follows:

- Professional learning opportunties that work *with* teachers supported them in implementing student-driven inquiry-based science instruction.
- Student-driven inquiry-based science instructional opportunities were created in diverse classroom contexts.
- Student-driven inquiry-based science instructional opportunities were created that afforded the creating of heteroglossic instructional spaces.
- Students were positioned to access diverse communicative and meaning-making resources.

The next sections elaborate these overarching findings relative to the synthesis of the research taken as a whole.

Working *with* teachers to implement student-driven inquiry-based science instruction

Central to our work with teachers, to work to refine the teacher workshop process, were opportunities to dialogue with teachers about their use of the instructional approach. This meant that in study design, as well as in process, we used dialogic forms of interacting with teachers. For example, focus-group interviews became resource sharing and community building opportunities. Data sources documenting instruction were not just delivered to the study, but also first were shared in person so that I could listen to the teachers' stories about instruction and gather their impressions of its use. In this way, the data collection was a dialogic process that afforded me opportunities to listen to the feedback and concerns of the teachers, and refine the professional development approach based on their voices (Siry, 2009).

We chose tools to collect teachers' impressions (open-ended surveys, teacher selected methods for lesson documentation) and processes (focus-group interviews) that specifically positioned us as researchers who could dialogue *with* teachers about how to best use this approach in their classrooms and with their students (Siry & Kremer, 2011). In this way, the dialogic teacher workshop refinement process positioned us to build from the voices of teachers to find the ways best suited to use this instructional approach. Relative to past IBSE dissemination projects, this study did not strive for teachers to implement a prescribed inquiry-based program. Rather, it sought to examine the ways that teachers *could* and *would* implement inquiry-based instruction in Luxembourg, and to establish with them through dialogue how to best support working with this type of student-directed instruction, which values diversity of voice.

This dialogic approach to working with teachers took time, and necessitated negotiation as we listened to teachers' feedback through recursive and iterative rounds of piloting and teacher workshops. There were times when teachers wanted to position us as the 'experts' who transmitted the instructional approach to them. This necessitated that we adapt our approaches to negotiate entry (Erickson, 2013) in conversations with them. This meant, for example, that at times I had to adjust the approaches I used to examine teachers' instruction. I had hoped at the outset of this study that we would be able to work in several teachers' classrooms. This however, did not materialize through our conversations with teacher participants. Teachers were more comfortable constructing detailed documentation themselves (through lesson logs, photo documentation, students' science journals, and class posters from investigations) in their own classrooms, and presenting this to us during focus group interviews after instruction. As a result, I needed to adjust the data collection methods I employed. Overall, I worked to ensure that there were multiple channels of dialogue with teachers throughout the research process. Next I turn to a discussion of the types of instructional opportunities created, in response to the first research question:

i. What types of instructional opportunities does Science Workshop, an inquiry-based student-driven science instructional approach, afford when used in Luxembourg primary classrooms?

Student-driven inquiry-based science instructional opportunities were created in diverse classroom contexts

As elaborated in Chapter 2, the IBSE instructional approach was implemented in a range of classrooms contexts. It is evident that even though teachers faced instructional time-restraints (one-hour of science instruction per week), and worked with students with a wide-range of linguistic competencies, all participating teachers were able to adapt the approach and support materials (sample lessons, integrated literacy activities) for use specific to the needs of their students. One example of adaptation is the use of the science notebook with younger aged-students. During one round of teacher workshops we presented the use of the science notebook as an essential tool to support integrated language and science learning in the context of the inquiry-based lessons. A group of teachers who taught six-year-olds commented that the tool was not appropriate for their instruction, as their students were just learning to write in German. After this, groups of teachers took the instructional approaches to their classrooms, tried them, and documented the process. In a resource-sharing focus-group session, a different group of teachers share student materials and their approach to using the tool. They adjusted the science notebook in ways that it could be used with students just learning to write, thus providing a model for how to adapt the science notebooks for use with all literacy levels. These resource-sharing sessions provided documentation the share with teachers about how to adapt the Science Workshop approach. This is particularly important in the Luxembourg context in that even though we are a small country, there is great linguistic and socioeconomic difference in the classrooms within a small region (Weth, 2015). Thus, an IBSE instructional approach that builds in flexibility is one way to honour and accommodate this diversity.

Science workshop supported inquiry-based science, which, in turn, supports the creation of heteroglossic instructional spaces

While Science Workshop did in fact support the construction of student-driven IBSE learning opportunities, I wish to go beyond these to discuss the heteroglossic nature of instructional opportunities revealed through the analyses presented.

In each of the three analyses, heteroglossic spaces that make room for voice and diversity were created, Thus, this study establishes that student-driven IBSE creates spaces for heteroglossia, and the use of heteroglossia to advance integrated science and language learning goals. This creation of heteroglossia withing monoglossic school policies is similar to a study elaborated by Flores and Schissel (2014) in the United States context. They describe the work of a bilingual literacy teacher who unofficially implemented heteroglossic instruction, which drew on Spanish and

English resources during an lesson that, according to school policy, was meant to be conducted in only English. The study presented in this dissertation builds from their work in two key ways. First, this study elaborated student-driven heteroglossic language and science resource use. Many prior studies, including that of Flores and Sichessel, focus on teacher-driven approaches. Thus, the instructional opportunities this study highlights contributes to the literature on the construction of heteroglossia-as-pedagogy (Creese & Blackledge, 2014) accomplished through a student-driven approach. Second, this study shows how this was accomplished in the unique context of Luxembourg primary schools. This builds on prior research conducted on heteroglossia in Luxembourg primary contexts (Mick, 2011), but extend the research base into science instruction. In summary, this study took a known approach to instruction, IBSE, and adapted it to the specific temporal, cultural tensions of the current Luxembourg primary system, to show how this approach can be used to construct instructional opportunities that are student-driven, and how to support teachers in using the program.

Moving from the first to the second research question,

ii. What does an analysis of student interactions in these contexts reveal about inquiry science instruction in multilingual classrooms?

Students were positioned to access resources to support their science learning in diverse ways

Interaction analysis revealed that students accessed varying semiotic resources at different points in instruction. This happened on numerous levels. First, at the meso-level students were given opportunities to voice questions and use these to design and conduct science investigations (Chapters 2, 3, and 4). Second, analysis at micro-levels revealed that students' accessed linguistic and semiotic resources differently across time in interaction (Chapter 3). Lastly, the analysis of student and teacher interactions, specifically in the context of the science notebook use showed different groups of students interacted in diverse ways with regards to notebook usage, and the interactions that surrounded its use (Chapter 4). In all, these three views revealed how students engaged in the instruction in diverse ways – both individual students through time and from group-to-group. Overall, students' interactions revealed a dialogic process of learning science that was constructed through a conversation between their interests and wonderings, and their science investigations.

Interesting, and particularly in the notebook analysis (Chapter 4), it was revealed that even though a dialogic pedagogical approach was used, students did not always position themselves to transfer their dialogic interactions into their written productions (science notebook entries), as was observed with one group in the interactions surrounding notebook use. The students' multiple ideas about their inquiries were also not revealed in conversations with teachers. Therefore, even though the teacher had structured instruction to be inquiry-based and student driven, there were times that the students' positions did not align with the dialogic nature of instruction, thus indicating an area of further exploration.

When taken as a whole, this study has demonstrated that adopting student-driven IBSE instructional approaches and research methodologies that aim to tease apart the interactions in these instructional contexts provides researchers and educators with opportunities to listen to teachers, and to students, and to see and hear the diverse ways they engage their voices in learning science without imposing monoglossic views of science learning and language use.

Implications

This study has implications relevant for research and teaching. I discuss these implications and their importance in the sections that follow.

Implications for research

Mainstream science education research, particularly in the top-tiered research journals, more often than not supports analysis of multilingual science classrooms through frameworks and methodologies that foreground students' and teachers' linguistic resource use. This is in part due to the roots science education, and education in general, has in the spoken (Lemke, 1990), and in psychological constructs that were historically the basis of science education research methodologies. Yet, there is still a dearth of research that teases apart the relationship of language and science learning. By this I mean research that views learning as occurring with and without the use of language, and the role of language in this process afterwards. Through the processes I engaged in while conducting the research I present in this dissertation, and in exploring my own experiences moving to Luxembourg and not being able to communicate using any of the three languages without losing my voice and then working to become plurilingual (Wilmes & Park, 2017), I have come to question the use of research methodologies that foreground the linguistic, particularly in multilingual classrooms.

Research methods that place language at the foreground can position plurilingual students at a disadvantage before analysis commences, if the methodology is coupled with frameworks that favour the use of specific national languages over the dynamic linguistic compentencies of plurilingual studnets. What I have come to see through this work is that when one starts with the verbal in Luxembourgish plurilingual classrooms, students can be positioned as deficit since the majority are not working in their home language. This work underscores this point and has implications for further work to examine possibilities to accomplish this.

Implications for teaching

First and foremost, this research demonstrates an instructional approach that is appropriate for use in Luxembourg public primary classrooms. Thus, given that it addresses the key points I elaborated in Chapter 1 specific to the Luxembourg context, Science Workshop is an instructional program can have implications by way of suggesting its future use with a wider group of teachers and classrooms. In fact, this has already started to occur. What has been learned from this project regarding the work with teachers to use student-driven IBSE has been the basis for further teacher professional learning opportunities offered by the University of Luxembourg with the with the support of the Fonds National de la Recherche (FNR) and the Luxembourg Ministry of Education. In 2016, SciTeach, a joint project between the University of Luxembourg, the FNR and the Luxembourg Ministry of Education, was launched. This education initiative has successfully established a science resource center, which offers teachers science instruction combined with material and coaching support. The lessons learned through the present study contributed, in part, to the professional learning opportunities now offered through SciTeach for Luxembourg primary teachers. More specifically, the ways of working with teachers, as well as the classroom examples of student-driven IBSE instruction from participating teachers have served as models in subsequent teacher workshops to be implemented in Luxembourg, and this has to be considered as a direct outcome of the present study. Thus, there is a direct link between the instructional approaches supported in this research, and future teacher science workshops.

The key lessons learned from this study regarding inquiry-based instructional methods have been further incorporated into the courses I have co-taught with Professor Christina Siry in the "Bachelor en Science de I'Éducation" program at the University of Luxembourg. In particular, in these courses we present our students the theoretical grounding for inquiry-based student-driven science instruction, and how it can be integrated with language learning. As a result of this study we now have models to share with the students from classes in Luxembourg that assist them in thinking critically about the benefits of such instruction. Then we support them in designing IBSE activities they can use in their future classrooms. Thus, what has been gleaned from this study has been put into immediate use to support additional teacher professional development, and pre-service teacher education offerings. This speaks to the societal implications from this dissertation, as demonstrated in its ability for direct use to further science education initiatives in Luxembourg.

Research Validation Processes

Before concluding, I return to a discussion of the ethical and substantive validation processes incorporated into this study that were introduced in Chapter 1. These were integral to the on going processes conducted throughout the research process.

Ethical validation

I worked toward ethical validation to ensure "that the debate is fair, that no one's voices are excluded or demeaned, and that the vested interests of the powerful, who end up having their way, are restrained" (Caputo, 1987, p. 260). In other words, I strove for multiplicity of voices to inform each research decision and analytical layer. For example, when analysing classroom interactions, multiple views were captured using video recording, additionally students' perspectives were revealed in interviews, and the research team's perspectives documented in team debriefs, were layered onto these interpretations. Multiple perspectives on one focal point were used in interpretation.

Ethical validation of interpretive inquiry also works to ensure the pragmatic value of a research study. The pragmatic value of a body of research, such as this dissertation, is as Gadamer (1994) elaborates, not judged by the researcher, but instead is judged the research's ability to lead to new questions and new dialogue. To this I answer in my own voice with a resounding *yes*. This work for me has been a journey that I started back when I was young, and paused only to write this dissertation, but that will continue on once I submit this dissertation. This research has led to new questions for myself, and my colleagues in Luxembourg, as we collectively consider and question the relationship between language and science learning. Creswell (2013) describes this as validation of research through its ability to support transformation and to lead to future action. This study has led to work with teachers in Luxembourg on using dialogic and inquiry-based science pedagogies.

I also turn to the dialogues that this research has opened between my research colleagues and myself, both in Luxembourg and in wider international education research circles. I am co-sharing a symposium on interaction analysis in multilingual contexts with colleagues from Spain and Israel, and Sweden at the 2017 annual meeting of the European Science Education Research Association (August 21st – 25th). In this way, the research I present herein has lead me to new questions about the relationship between language and learning in multilingual contexts, and the use of pedagogies that position students to access diverse voices and resources as they engage in science learning.

I turn to the impact this work has had on science teacher workshops following that build from the work I present here, and the creation of the SciTeach Center as speaking to the pragmatic value of this dissertation. Thus the pragmatic value of the research I present here has been shown in that what has been learned here regarding IBSE instruction in multilingual classroom contexts in Luxembourg has been used for further work with teachers.

Substantive validation

Substantive validation involves working toward trustworthiness or goodness of an interpretive study (Angen, 2000). I incorporated substantive validation processes at several different points in the research process. During data collection, I worked to gather information using more than one perspective, or source. Classroom instruction was viewed using whole class and small group videos, providing multiple angles and perspectives. Interviews were collected in order to provide space for students' voices to sit alongside those of the teachers using Science Workshop. These multiple perspectives afforded opportunities to search for similar themes and patterns across multiple data sources from multiple perspectives. An example of this occurred while I analysed teachers' perspectives of the instructional opportunities they created in their classrooms. I compared teachers' self-reported lessons through surveys and focus group interviews to our own experiences co-teaching Science Workshop. In this way, I was able to compare our own impressions with those of teachers, and to draw lines of similarity and difference among them.

During analysis I shared analytical descriptions and emerging findings, with several other researchers at regular intervals. This was done through informal meetings, formal presentations, sharing research manuscripts with colleagues, and through peer-reviewed conference submissions and manuscripts. These substantive processes provided me with feedback on the quality of the analysis I conducted and provided me with feedback to adjust approaches, processes, and interpretations.

Van Manen (1990) explains that the complexity of a research topic can be addressed by considering various intersubjective understandings of a topic. Overall, the manuscript style of this study afforded me the opportunity to incorporate analysis from both views of teachers and teaching in classrooms, and through these multiple views, analyse the instructional opportunities afforded by this IBSE instructional approach and its use in Luxembourg primary classroom contexts.

Research Challenges and Opportunities

The research I present here resulted from a series of decisions that unfolded in my time working with teachers and in classrooms. There were, of course, other paths that emerged that I could have taken. These would have lead to the expansion of different components of this research, and the reduction of some I report on here. I elaborated on one such point in a prior section regarding my ability to work in classrooms with teachers. Initially I envisioned data collection would allow me to work in several classrooms directly and to videotape instruction as it unfolded. There was a process of negotiating entry and relationships with teachers participating in the project (Erickson, 2013; Tobin, 2015) that was built upon throughout the entire process to ensure I honoured the wishes of participants. For example, at the outset I was hoping to observe and videotape instruction in participating of the classrooms. In discussing this with many of the teachers during workshops, it became clear that they were not comfortable with this. I was faced with the challenge of eliminating these additional classroom views from my research protocols. For me, and for my research, this was a crucial component of "negotiating entry" (Tobin, 2015, p. 34) that positioned me as a welcome guest, not as a forced observer. Thus, the entire process was a dialogic negotiation between the participants and myself, and at no time did I want teachers or students to feel that our research team, or I were forcing ourselves into their practices.

An additional challenge that transformed into an opportunity was my orientation to working with plurilingual participants. Throughout the research and analysis process, it was a challenge to ensure I was understanding and interpreting what was being communicated, due to my differing comfort levels with Luxembourgish, German, and French. I worked to build in processes to support my understanding of what was being said, and the nuances of what was being communicated. At first, processes which I used to ensure I understood what was spoken, became opportunities for me to view my data sources through multiple layers of understanding, leading me to refine my analytical approaches. In the end, what began as a challenge was transformed into an opportunity to deconstruct my orientations, biases, and views of language and communication.

Suggestions for Future Research

There are multiple paths that stem from the findings I present here. Angen (2000) explains that qualitative research, "must provide an invitation to continue the conversation and to take the dialogue in new and more fruitful directions" (p. 389). I can envision several ways to continue the dialogue I have begun with this dissertation related specifically to inquiry-based teaching in multilingual classrooms in Luxembourg, and regarding the interplay of language, learning, and interactions in general.

First, would be to return to the existing data corpus and to analyse additional sets of data, for example the videos from teacher workshops, and from teacher focus-group interviews. There are many lines of thinking that began to reveal themselves in my analysis, which still remain unexplored and for which the data sets have already been collected. One such line of investigation would be to examine teachers' positions toward integrating science and language literacy through more extensive literacy tasks in the context of IBSE lessons. As I performed analysis on the teachers' feedback surveys, and listened to the teacher videos, I began to hear different perspectives on the use of inquiry for science instruction, which can be conceptualized on a scale of *more student–directed* or *more teacher-directed*. It also started to emerge in my conversations with teachers that they held positions that literacy integration was a natural fit to with science instruction, but that student-directed inquiry was more challenging. While these were both goals of this program, I started to hear and see that there was divergence on these two views of integrated inquiry instruction. It would be worth returning to the data corpus to explore these lines of thinking more, and to see how this is reflected, or not, in the learning products from the teachers' classrooms.

Another line of research with merit to pursue would be to analyse the teacher workshop and focus-group interviews using a lens of Interaction Ritual Theory. This would build off upon the research of Siry (2009) that examined synchrony in teacher's interactions in a teacher education course, in the short term, and the resulting forms of solidarity that formed. Several times during focus-group interviews that high levels of synchrony formed among the members of the group. Interestingly, teachers shared stories about teacher-directed science activities they conducted.

Initial viewing and reflecting leads me to conclude that the teacher workshop videos collected during this study could be analysed using IRT techniques, such as I performed in the analysis of classroom interactions, presented in Chapter 3, and in ways that apply to recent work published by Olitsky (2017).

In her study recently published in the *Journal of Research in Science Teaching*, she demonstrates that educators working together move towards transformation of instructional practices at moments when solidarity breaks down and conflict arises. She analyses the interactions that unfold in these moments of breakdown using Interaction Ritual Theory (Collins, 2004) as a methodology to reveal how these interactions occur on micro-scales. It could be theoretically beneficial to explore these moments of solidarity creation, and breakdown in workshops with teachers in Luxembourg.

It would be theoretically and practically advantageous to pursue additional research investigating the use of Science Workshop (inquiry-based science and science notebooks) more widely in Luxembourg. This would allow me to expand the findings I present here, but across a wider group of schools, and to add more voices to the conversation on how to incorporate such teaching pedagogies into Luxembourg primary schools.

Personally, I was fascinated with the number of issues surrounding language and working in multilingual contexts that arose during my dissertation process. One such question, for example, is the representation of "mixed" resource use in transcriptions and translations. While there exists literature that elaborates such issues, I think it would be an intellectually stimulating experience to follow this vein of research in the linguistically dynamic and rich contexts of Luxembourg primary schools This would build on the work of scholars such as Roth and Lawless (2002) who examined the intersection of language and gestures when students worked with science investigations, and the language that can develop from student interactions during science instruction.

Concluding remarks

In conclusion I end with a call to educators and researchers everywhere, in both multilingual and monolingual contexts, with words from Miller an Israeli special education teacher to "remember always that education is the forming of impressions on souls" (Miller, 2016). With this in mind I ask, what impression is it that we want to leave on the souls of our children when they leave primary school? What impression of science? What impression of their voice? Is it one where they are told what is scientifically important, and how to make sense of it? Is it one that forces them to communicate in a language that they have not yet mastered? Or rather, do we desire to lift their voices? Do we want to help them construct an impression that they have a voice in science, that their world view matters and that their voice can add to understanding and tackling the scientific challenges of their generation? It is this view that this dissertation supports. I join with the voices of researchers who call upon us as educators, and as informers of educational policy, in offering up the research I detail here as an example of an educational approach where de Saint-Georges and Weber (2013) explain,

> we show more care for others in this world of diversity and in which we acknowledge their special and unique value to us, rather than attempting to tame or make invisible the diversity of repertoires and practices. (p.8)

When we position students to learn science from their own questions, in ways that allow them to access their diverse repertoires as resources, we leave them with an impression of the importance of their voice, with the hope that they may use that voice toward understanding and solving the scientific challenges of their generation.

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Appendix A – Sample Participant Consent Form – for student participants

UNIVERSITÉ DU LUXEMBOURG

Fonds National de la Recherche Luxembourg

Assessing Changes in Students' Questions Following the Switch to Inquiry-Based Science Education (ACQUIRE)

Cher élève/chère élève:

Nous allons mener une étude sur la créativité et l'apprentissage des sciences dans votre classe. Nous faisons cette étude avec des étudiants dans différentes écoles au Luxembourg.

Afin de mener cette étude, une chercheuse filmera quelques leçons de sciences dans ta classe. L'enseignant et tes parents ont consenti à ce que tu participes à cette étude. Mais tu peux aussi décider pour toi même si tu veux en faire partie.

Toutes les informations recueillies seront traitées de manière confidentielle et elles seront « anonymisées ». Cela veut dire que nous n'utiliserons pas ton vrai nom et que personne qui verra les photos, vidéos ou autres choses que nous recueillerons, ne saura qui tu es ou quelle école tu fréquentes. Toutes les informations que nous recueillerons seront archivées dans la base de données informatisée et sécurisée de l'unité de recherche E.C.C.S à l'Université du Luxembourg. Uniquement les chercheuses et la directrice du projet, Prof. Christina Siry, auront accès à la base de données sécurisée.
Les résultats de cette étude seront uniquement utilisés dans le cadre de conférences scientifiques et la rédaction d'articles scientifiques.

La participation à cette étude est volontaire et tu peux choisir de ne plus vouloir participer à tout moment sans devoir donner une raison. Si tu veux t'arrêter, tu peux dire à la chercheuse, à ton enseignant ou à ton parent que tu n'y veux plus participer.
Si tu as encore des questions, tu peux les poser à la chercheuse du projet (indiquée ci-dessous).

Afin de pouvoir faire cette étude, nous avons besoin de ta signature. Tu peux le faire en signant ton nom ci-dessous. Si tu veux y participer, nous te remercions pour ton aide à mieux comprendre le enseignement et l'apprentissage des sciences.

En cas de questions, tu peux demander:
Name: Ms. WILMES (sara.wilmes@uni.lu)
……………………………………………………………………………………………

Par la présente, je soussigné(e) ______________________________ donne mon accord qu'une chercheuse de l'Université du Luxembourg me documente et enregistre les données dans une base de données interne et sécurisée de l'unité de recherché E.C.C.S. et l'utilise dans le cadre de publications et de présentations scientifiques

□ Je suis d'accord

□ Je ne suis pas d'accord,

Date: Signature:

Appendix B – Sample Participant Consent Forms – for teacher participants

UNIVERSITÉ DU LUXEMBOURG

Fonds National de la Recherche Luxembourg

Assessing Changes in Students' Questions Following the Switch to Inquiry-Based Science Education (ACQUIRE)

Cher enseignant, chère enseignante:

La présente étude enquête sur le enseignement et l'apprentissage des sciences dans des classes multiculturelles dans différentes écoles au Luxembourg.

Afin d'effectuer cette étude, la chercheuse enregistrera des activités scolaires régulières concernant le enseignement et l'apprentissage des sciences :

- Deux à six leçons de sciences et/ou des leçons basées sur la recherche d'informations seront documentées en vidéo et audio.
- Les enseignant(e)s sont demandé(e)s (ensemble dans un groupe) de témoigner sur des moments vidéo en classe dans un interview.

Cette étude fait partie d'un projet de thèse de doctorat à l'Université du Luxembourg. Toutes les données seront traitées de manière strictement confidentielle, les données seront anonymisées, tous les noms originaux des individus seront remplacés par des pseudonymes. Les données seront archivées pendant 10 ans dans la base de données sécurisée de l'unité de recherche E.C.C.S (Education, Culture, Cognition and Society). Uniquement les chercheuses et la directrice du projet, Prof. Christina Siry, auront accès à la base de données sécurisée.

Les résultats de cette étude seront utilisés uniquement dans le cadre de conférences scientifiques ou pour la rédaction d'articles scientifiques.

Afin de pouvoir effectuer cette collecte de données dans votre classe, nous avons besoin de votre consentement par écrit. Vous pouvez le faire en signant la déclaration ci-dessous. Avec votre permission, nous vous remercions pour votre contribution à une meilleure compréhension du enseignement et l'apprentissage des sciences.

Veuillez trouver ci-joint un résumé des points de préoccupation principaux de l'étude:

Sens: Cette étude cherche à mieux comprendre le enseignement et l'apprentissage des sciences dans des classes multiculturelles dans des écoles au Luxembourg.

Procédures: Pendant cette étude vous pourriez être enregistré(e)s par vidéo ou audio. Vous pourriez être demandé(e)s de participer à des interviews. Des extraits des vidéos seront utilisés dans la dissémination de ce qui a été trouvé par cette étude, uniquement pour des besoins scientifiques.

Risques: Il n'y a pas de risques potentiellement désavantageux relative à la participation à cette étude. Les activités prendront place dans le cadre des activités de classe normales.

Retrait : La participation à l'étude est volontaire. Si vous décidez d'y participer, vous pouvez vous retirer à tout moment sans conséquences.

Anonymat : Tous les vidéos, interviews et travaux en classe dans lesquels vous et vos élèves sont impliqués seront anonymisés. Cela veut dire que les noms des élèves et enseignant(e)s seront effacés des vidéos. Toute information recueillie sera stockée et verrouillée sous protection avec mot de passe, afin que personne d'autre que la chercheuse et la directrice de projet ne puisse avoir accès aux informations.

Droits de sujet : Si vous avez des questions concernant vos droits ou ceux de vos élèves en tant que participants à cette étude, vous pouvez contacter le comité de revue éthique de l'Université du Luxembourg par e-mail (erp@uni.lu) ou la chercheuse sur le projet (indiquée ci-dessous).
Personne à contacter en cas de questions concernant tout aspect de votre participation :

Nom: WILMES Sara
Position: Fellow Doctoral Student E.C.C.S
Université du Luxembourg
henderika.devries.001@student.uni.lu

Par la présente, je soussigné(e) ____
donne mon accord qu'une chercheuse de l'Université du Luxembourg documente des activités dans ma classe et enregistre les données dans une base de données interne et sécurisée de l'unité de recherché E.C.C.S. et l'utilise dans le cadre de publications et de présentations scientifiques.

□ Je suis d'accord

□ Je ne suis pas d'accord,

Date: Signature:

Relevant Publications and Presentations From the Dissertation Period

Publications

Wilmes, S. E. D. & Siry, C. (in review in the journal *Science Education*). Interaction rituals and inquiry-based instruction: Analysis of student participation in small-group investigations in a multilingual classroom.

Wilmes, S. E. D., Siry, C., Gómez Fernández, R., & Gorges. A. (in press). Reconstructing Science Education within the Language | Science Relationship. In L. Bryan & K. Tobin (Eds.), 13 Questions: Reframing Education's Conversation: Science. NewYork, NY: Peter Lang.

Wilmes, S. E. D. (2017). Science Workshop: Let Their Questions Lead the Way. In *Science Teacher Preparation in Content-Based Second Language Acquisition* (pp. 323-340). Dordrecht, Netherlands : Springer.

Park, J. & **Wilmes, S. E. D.** (accepted with revisions). A critical co/autoethnographic exploration of self: Becoming science education researchers in diverse cultural and linguistic landscapes. In C. Siry & J. Bazzul (Eds.), *Critical Voices in science education research: Narratives of academic journeys*. Dordrecht, The Netherlands: Springer

Bryce, N., **Wilmes, S. E D.**, & Bellino, M. (2016). Inquiry identity and science teacher professional development. *Cultural Studies of Science Education*, *11*(2), 235-251.

Siry, C., **Wilmes, S. E. D**., & Haus, J. M. (2016). Examining children's agency within participatory structures in primary science investigations. *Learning, Culture and Social Interaction*, *10*, 4-16.

Presentations

Wilmes, S. E. D., Siry, C., Gomez Fernandez, R., Gorges, A. (accepted, June, 2017) *Problematizing video analysis rooted in the verbal: examples from culturally and linguistically diverse and science classrooms*. Association for Visual Pedagogies annual conference, Aalborg, Denmark.

Wilmes, S. E. D., & Siry, C. (August, 2017). *Interaction Rituals in Multilingual Student-Centered Science Instruction*. European Science Education Research Association, annual conference, Dublin, Ireland.

Wilmes, S. E. D., & Siry, C. (August, 2017) *Multimodal Wonderings*. European Science Education Research Association annual conference, Dublin, Ireland.

Park, J. & **Wilmes, S. E. D**. (2015) A Co/Authoethnography Exploration of Self: *Becoming Science Researchers in Culturally and Linguistically Diverse Contexts*. Korean Association for Science Education annual meeting, Seoul, Korea.

Wilmes, S. E. D. & Park, J. (2015) Becoming Researchers in Mulilingual Contexts: A Co/Autoethnographic Exploration. In the symposium, *International Perspectives on Multilingual Contexts in Science Education Research and Practice*. National Association of Research in Science Teaching, Chicago, IL, USA.

Park, J. & **Wilmes, S. E. D. (2015).** Science education researchers in multilingual contexts: A co/autoethnographic exploration of lagnauge, positioning, and self. In the symposium, International Perspectives on Multilingual Contexts in Science Education Research and Practice, August 31 – September 9, Helsinki Finland.

Wilmes, S. E. D., Siry, C. & Hilgers (Haus), J. (2015). The role of wonderings in inquiry-based science education: Expanding the notion of questions. European Science Education Research Association annual conference, August 31 – September 9, Helsinki Finland.

Siry, C. and **Wilmes, S. E. D.** (2013). *Working with Inservice Teachers to Develop CPD: An Emergent, Responsive Approach to Teacher Professional Development.* National Association of Research in Science Teaching, Annual International Conference, Rio Grande, Puerto Rico, USA.

Invited Talk

Siry, C. **& Wilmes, S. E. D.** (November 2013) Designing Science Professional Development WITH Teachers: An emergent, responsive approach in a time of inquiry-based science dissemination. Stockholm University.