**INVESTIGATING 6TH GRADERS' USE OF A TABLET-BASED APP SUPPORTING SYNCHRONOUS USE OF MULTIPLE TOOLS DESIGNED TO PROMOTE COLLABORATIVE KNOWLEDGE BUILDING IN SCIENCE**

by

Carrie-Anne Sherwood

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Doctoral Committee:

       Professor Annemarie Sullivan Palincsar, Chair
       Professor Joseph S. Krajcik
       Professor Jean P. Krisch
       Professor Brian J. Reiser, Northwestern University

**DEDICATION**

This dissertation is dedicated to my former students from M.S. 80, Bronx, NY, and Codman

Academy Charter Public School, Dorchester, MA.

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There are so many people who have supported me on this journey. I would first like to thank Annemarie Palincsar, my adviser. She took me on as an advisee the summer after my first year, and has nurtured and encouraged me ever since. I will always appreciate her calm demeanor, and tact, particularly at times when I was "concerned" (read: panicked!) about something or other related to my dissertation. A great listener, she always knew the right thing to say in those moments when I needed guidance and grounding. When it came time to choose a dissertation topic, I had the option to continue with a research project for which I had already done a lot of work. But I told her I wanted to 1) work more directly with her, and 2) do an intervention study where I could be a part of the classroom data collection. It was fortuitous that she and Elliot Soloway had just submitted an EAGER grant, and brought me into what became the *WeInvestigate* study, and my dissertation. To that end, I would also like to thank Elliot, who was also incredibly encouraging throughout this dissertation process. As a "newbie" to the educational technology field there were times when I was not sure that what I was doing had value within the research community. Elliot was always there to insist that it did. These moments of reassurance, and his infectious enthusiasm, went a long way toward keeping me going, especially toward the end.

I would also like to acknowledge the rest of my committee. Joe, my original advisor at Michigan, involved me in two very different research projects from which I learned a lot about conducting educational research. I was able to utilize this learning in my dissertation data

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I argue in my dissertation that K-12 students should be engaging in certain practices because they are practices in which scientists engage. Therefore, it was very important to me that a scientist be on my committee. Jean Krisch is an amazingly sweet, extremely knowledgeable, and surprisingly spry physics professor who is also passionate about and committed to science education. I am so thankful for her bringing a scientist's perspective to my work. I am also thankful for her occasional note of encouragement and appreciation for the work that we as educators do.

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I wish to acknowledge the friends I have made on this journey, many of whom are or were on this same Ph.D. journey. Diana, Annick, Emily, Viki, Betsy, and Leanne – I feel like you all have been with me in various ways since that terrible, painful breakup in our first year. All of your wisdom, humor, generosity, and caring have helped me get through these past five years. Ingrid, my sister from another mister, my first year you sent me a note of encouragement after one of our classes, and we have been friends, and conference roommates, ever since. There is so much I could say - but not enough space in which to say it - about the ways that you all contributed to my emotional and intellectual wellbeing over the years. I feel as though I have made lifelong friends in you all, and I cannot wait to see how our lives continue to unfold. I definitely could not have done this without you all, and I am truly blessed that you are in my life.

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and allowed for and accepted the times when I did not behave like the Carrie-Anne they all knew and loved. From the time that I was young, they have always encouraged me, told me I was strong, determined, focused. That I could handle this. I would say that I drew my strength from their support, and with that, I DID handle this! Thank you, and I love you all very much!

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**Abstract**

At this pivotal moment in time, when the proliferation of mobile technologies in our daily lives is influencing the relatively fast integration of these technologies into classrooms, there is little known about the process of student learning, and the role of collaboration, with app-based learning environments on mobile devices. To address this gap, this dissertation, comprised of three manuscripts, investigated three pairs of sixth grade students' synchronous collaborative use of a tablet-based science app called *WeInvestigate*. The first paper illustrated the methodological decisions necessary to conduct the study of student synchronous and face-to-face collaboration and knowledge building within the complex *WeInvestigate* and classroom learning environments. The second paper provided the theory of collaboration that guided the design of supports in *WeInvestigate,* and described its subsequent development. The third paper detailed the interactions between pairs of students as they engaged collaboratively in model construction and explanation tasks using *WeInvestigate*, hypothesizing connections between these interactions and the designed supports for collaboration. Together, these manuscripts provide encouraging evidence regarding the potential of teaching and learning with *WeInvestigate*. Findings demonstrated that the students in this study learned science through *WeInvestigate*, and were supported by the app - particularly the collabrification - to engage in collaborative modeling of phenomena. The findings also highlight the potential of the multiple methods used in this study to understand students' face-to-face and technology-based interactions within the "messy" context of an app-based learning environment and a traditional K-12 classroom. However, as the

third manuscript most clearly illustrates, there are still a number of modifications to be made to the *WeInvestigate* technology before it can be optimally used in classrooms to support students' collaborative science endeavors. The findings presented in this dissertation contribute in theoretical, methodological, and applied ways to the fields of science education, educational technology, and the learning sciences, and point to exciting possibilities for future research on students' collaborations using future iterations of *WeInvestigate* with more embedded supports; comparative studies of students' use of synchronous collaboration; and studies focused on elucidating the role of the teacher using *WeInvestigate* - and similar mobile platforms - for teaching and learning.

# CHAPTER I

## Introduction

### Background and Rationale

As they have for many years now, digital technologies will continue to influence the lives of most individuals. Effective citizens and workers must be able to exhibit a range of functional and critical thinking skills, currently regarded as "21$^{st}$-century skills," related to technology (NRC, 2010; P21 December 2009). Thus, calls for the integration of technologies in schools are ubiquitous, and the federal and state governments, as well as local school districts and private technology firms, have deployed massive funding efforts toward equipping classrooms with internet connectivity and computers, particularly the more mobile, less bulky tablet computers (e.g., Los Angeles United school district's iPad initiative). Recent education trends such as Bring Your Own Device (BYOD) (e.g., Raths, 2012), "blended learning" (e.g., Horn & Staker, 2011), "one to one instruction" (e.g., Penuel, 2006; Chan et al., 2006) and "flipped classes" (e.g., Horn, 2013)," reflect this public demand for technology in schools, and have led to increased popularity in the use of mobile devices in K-12 educational settings (Banister, 2010).

Currently, a wide variety of apps for use on tablet computers are being developed specifically for educational purposes, and many curriculum developers see tablets as the next frontier for their products. There have not yet been many K-12 research studies on the functionality and effectiveness of apps or tablet computers for student learning (see e.g., Enriquez, 2010; Chen et al., 2012 for college-level studies). In a review of apps designed to run

on iPad and other iOS devices, Murray and Olcese (2011) found that most of the apps involved students' consumption of content, rather than the creation of - or collaboration around - that content.  At the time of their study, not a single app, in their evaluation, considered current understandings about how people learn (Murray and Olcese, 2011). Thus, there is very little known about the process of student learning and collaboration with app-based learning environments on mobile devices, especially for our purposes as science educators, on apps that are meant to engage students in the kind of ambitious depiction of science instruction that is captured in current reform documents such as the *K-12 Frameworks for Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

Despite the dearth of research evidence, school districts are investing large amounts of money in technology-based or technology-integrated curricula. A major criticism, even possibly a fear, of the current calls to integrate more technology in classrooms is that it will isolate students, and reduce, or eliminate, the social benefits of learning (Rotella, 2013).  The media fuels the debate by publishing images of rows of students, each staring at his or her own computer or tablet, not engaging with peers or a teacher, or receiving their lessons from a pre-recorded lecture online.  Developing and testing technologies that directly address the presumed or anticipated isolation of students, such as technologies that encourage and support student collaboration, seem like a viable way to alleviate these concerns.

Effective collaboration is currently regarded as an essential "21st century skill," and is increasingly necessary in the lives of adults (Kuhn, 2015; Dede, 2010; NRC, 2010; P21 December 2009). Although it is a widely-held belief that peer collaboration has benefits for students' intellectual advancement (e.g., Brown and Campione, 1994; Hoadley & Linn, 2000; Scardamalia & Bereiter, 1996), the evidence in support of its effectiveness is not consistent

(Kuhn, 2015). Additionally, at this pivotal moment in time, when the proliferation of mobile technologies in our daily lives is influencing the relatively fast integration of these technologies into classrooms, there is less known about the role of collaboration in technology-rich classrooms, particularly when at least some of the collaboration occurs *through* the device (Kim et al., 2007; Lipponen, 2002). In particular, for our purposes as science educators, more research is needed to understand the collaborative discourse patterns of students within a technology-based science-as-practice learning environment, in the context of naturalistic (classroom) settings (Waight & Abd-El-Khalick, 2007; Lipponen, 2002).

Responsive to current reforms in science education (NRC, 2012; NGSS Lead States, 2013) and educational technology (NRC, 2010; P21 December 2009), and to this need for more studies on K-12 students' learning and collaboration with technology-based, specifically app-based mobile learning environments, this dissertation presents findings from an overall exploratory study of sixth grade students' collaborative use of a tablet-based science app called *WeInvestigate*.

The *WeInvestigate* digital learning environment - a kind of computer supported collaborative learning (CSCL) environment - is an application ("app") for use on a tablet computer, designed to support students' collaborative engagement in learning science content and practices within a real-world context. In colloquial terms, it is a "fat app" - it is comprised of several applications, which are "collabrified" - WeModel (a drawing app), WeWrite (a text editor), WeRead (an ebook reader), WeWatch (a video player); furthermore, it plays simulations. Screenshots of these modules can be found in Chapter 3 (Manuscript 2). We use the term "collabrified" to mean that the app enables multiple students to work together synchronously,

while each is on his/her own tablet. A more detailed description of the *WeInvestigate* app will be discussed in Chapter 3 of this dissertation.

## Research Purpose

The overall purpose of the dissertation was an exploratory study of the *WeInvestigate* learning environment. More specifically, the focus of this dissertation centered around one aspect of the environment, student collaboration, and how collaborative learning, supported by a model-based science curriculum that was designed to be integrated with and leverage specific functionalities of the technology, supported peer interactions, and facilitated knowledge building among pairs of sixth grade students. We sought to study the feasibility of embedding an entire well-researched, innovative curricular unit into a single app for use with mobile devices; to investigate the synchronous collaborative capabilities of students using the app to engage in scientific practices; and to study student learning outcomes within a context where the teacher and students had not previously engaged in teaching and learning science in this way.

The overarching research question guiding this pilot study of the *WeInvestigate* learning environment was: **How does a digital, mobile learning environment support students' collaboration and knowledge building as they engage in the practices of constructing science models and model-based explanations?**

## Theoretical Framework

This dissertation study takes the stance that students should engage collaboratively to do their work in science class because it is authentic to the work of scientists, and to engage in this practice of science helps to enculturate students into more deeply learning science content (Brown, 1995). Developing a deep understanding of science as a social enterprise, as current reforms suggest, entails engaging students socially in the practices of science. This stance is

aligned with an overall social constructivist perspective of student collaboration. The social-constructivist paradigm maintains that knowledge is socially constructed, and that learners should be involved in a process of collaborative knowledge construction to achieve conceptual change (Vygotsky, 1978).  In this sense, learning is knowledge construction.  Viewed somewhat differently, learning is also a process of enculturation (Brown, Collins, & Duguid, 1989), or of becoming a member of a community of practice (Lave, 1991).  Learning science, for instance, entails learning to become part of the community of science, which means doing science in authentic ways. Authentic activities are considered "the ordinary practices of a community," or the work that practitioners, or experts, of that community do (Brown et al., 1989, p.34). For this dissertation, "authentic" science classroom activities are those in which students are engaged in practices that mirror the work of scientists, and do so in relevant, meaningful contexts.

From this situated cognition perspective, conceptual knowledge cannot be abstracted from the situations or contexts in which it is used and learned. Learning occurs naturally through activities, contexts, and community interactions (Lave, 1991).  Figure 1.1, below, graphically represents the situated context in which the teaching and learning in our study occurred.

More specifically, the design work and analyses in this dissertation are grounded within the principles illustrated by Scardamalia and Bereiter's Knowledge Building approach (e.g., 1994), which positions itself within the social constructivist paradigm, and resembles many principles of situated cognition. The basis of knowledge building is that authentic, creative knowledge work can take place in school classrooms. In other words, although students are learning already existing knowledge (when compared to what scientists already know), they can engage in the work that not only mirrors the knowledge and practices of disciplinary experts (i.e., scientists), but also advances the state of knowledge of the classroom community (when

compared to the knowledge that students enter a science classroom with). Knowledge is distributed such that no one individual knows it all, and students come to school knowing different things, making for more interesting and productive exchanges between them. Therefore, collaboration is necessary for knowledge building (Brown, 1994). More detail on our theoretical approach to the design of the *WeInvestigate* learning environment can be found in Chapter 3.

## Study Context

Mentioned previously, Figure 1.1. represents the context in which this dissertation study was situated. Each of the "levels" relevant to this study are nested within, and interact with, each other.



*Figure 1.1.* Representation of the situated nature of the study activities.

### The Curricular Context

Beginning in the center of the graphic, the curricular context consisted of the written curriculum. The written curriculum consisted of texts and model-based activities to support student learning of physical science concepts. The texts were adapted from a variety of sources, and the activities and driving question were adapted from the IQWST "Smells" unit (Krajcik et al., 2013). Reflective of current reforms, the written curriculum engaged students in the scientific

practices of constructing models, and writing model-based explanations. Text-based supports for student collaboration as they engaged in these practices to learn the science concepts were embedded into the written curriculum comprising the curricular context. Also included at the curricular context "level" is the teacher's guide, which was created to be educative for the teacher (Davis & Krajcik, 2005), to support her in supporting students in the ambitious kind of teaching and learning depicted in the curricular text.

**The Technology Context**

The curricular context was developed synergistically with the development of, and nested within, the technology context, the next level on the graphic. The technological context comprised the app itself, which was made up of modules with different functionalities (WeModel, WeWrite, WeRead, and WeWatch), as described above. The students utilized these different functional spaces to engage with the texts and activities of the embedded curricular context. Further, these spaces were collabrified - a crucial component of the technological context thought to support student collaboration. The technological context was situated within the classroom context. More about the curricular and technological contexts can be found in Chapter 3.

**The Classroom Context**

The teacher and students exist at the classroom context "level," and the work they do spans all of the levels of the graphic. Although this dissertation was a study of students - specifically students' collaborative interactions as they engaged with *WeInvestigate* - the teacher's role in any kind of classroom instruction cannot be overlooked, more information about the teacher's background will be presented here to provide additional context. Included in Chapter 3 (section 3.3) is a discussion of the design of the teacher's guide for *WeInvestigate*,

which reflected the anticipated role the teacher would play during this study. Chapter 5 provides some discussion of the teacher's role during implementation, and implications for the future for teachers using similar technologies.

**The teacher.** The teacher-participant in this dissertation study, Ms. Jones[1], is White and had 14 years of teaching experience with a standard certificate. She has a master's degree in education (with a science concentration) and an undergraduate science degree in natural resources. Before becoming an elementary teacher, Ms. Jones had worked for over ten years as a science educator in both formal and informal settings, and with a variety of age ranges.

In an interview that took place before the study began, Ms. Jones described her teaching style as "pretty structured." She admitted that she did "very little" hands-on activities, but also pointed out that the study year was the first year she had been so hesitant to do hands-on stuff with her classes, due to some student behavior issues. Instead, Ms. Jones' class was very much focused around science texts, particularly more traditional science textbooks. Each class often involved reading the textbook together, then engaging in some sort of teacher-led note-taking.

Ms. Jones self-reported a limited knowledge of and ability with technology, which she cited as the primary reason for her limited use of technology in her instruction. When she did use technology in her instruction, she primarily used Powerpoint, which she suggested she used "a lot." She also allowed her students to use computers when there was a specific website she wanted them to see (e.g., Brainpop), or if she wanted them to do some research, for which she provided for her students a limited list of acceptable websites. More often, she simply projected from her classroom computer onto a SMART Board the particular website or simulation she wanted her students to see.

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[1] A pseudonym

Though in the classroom the students were seated in groups at tables, Ms. Jones explained that she did not use a lot of collaboration in her science instruction. However, she did set up expectations for collaboration with her students at the beginning of the year, which she said she reviewed with her students each time they were expected to collaborate. Her expectations included suggestions, such as, "respectful, quiet talk" and "everybody has to say something." When she would ask her students to collaborate, it was rarely in groups larger than three students, and it was usually for "little brief things," such as having her students turn to the student next to them and decide which answer was the best one. For the particular class that she chose to participate in this study she said that, at that time, in January of that school year, she was "still trying to teach them not to say 'shut up' to each other, and as they're moving through the room are  treating each other respectfully." Though she did express a certain skepticism about requiring the students to collaborate for this study (she asked if we ever thought about doing the project without collaboration), she was also genuinely interested in seeing how it would work.

**The focal students.** Also at the level of the classroom context were the focal students, who were chosen by the teacher. Ms. Jones identified six students from her class that would be the students of focus for this study: Mary, Hannah, Marcel, Quentin, Uma, and Rose[2]. She chose them based on their school attendance, reading levels, behavior, and grades. She described the six original focal students as some of the "best" students in the class both academically and socially. They were also some of the "strongest" readers in the sixth grade. Because Ms. Jones's science class was, for the most part, a text-based class, these students' strong reading comprehension of the science textbook generated "A" or "B" grades in science. Students interacted with their teacher, and collaborated with one another both face-to-face and through the

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[2] All pseudonyms

app (technological context) as they engaged constructing models and model-based explanations, while being immersed in the physical science content of the curriculum (curricular context).

**The School and District Contexts**

All of the nested contexts shown in Figure 1.1. were further situated within the school and district contexts. The dissertation study was conducted in one sixth-grade classroom in a small city in the Midwest. This sixth grade was situated in a grade 2-6 Elementary School.  The school is both socio-economically and racially/ethnically diverse: 72% of children are eligible for free or reduced lunch; 63% of students are African American, 23% White, 11% Hispanic, and less than 3% American Indian/Asian/Pacific Islander.  The school had seen a steady increase in the number of English Language Learners over the past five years.  When compared to students across the State, the students in this school historically underperformed on the State's standardized exams, across all categories.  From June 2010-January 2012 the school experienced a turnover in building leadership three times.  According to the school's 2013-2014 Strategic Improvement Plan, the "staff is undergoing a paradigm shift in regards to classroom instructional practices, school culture, behavioral plans, incorporation of technology into instruction, and project-based learning."

The summer before the school year in which this study took place, the district in which the study school was located merged with a neighboring, also under-resourced, school district with the goal of being better able to address economic and academic challenges. This consolidation of school districts contributed to upheaval in the school system, including teachers losing, then having to reapply for, their jobs. Our teacher-participant was subject to this process. The upheaval and disorganization of the resulting school district, in part, contributed to her making the decision to retire halfway through the school year, at the beginning of the study.

Although she was still committed to participating in and completing the study, her decision to retire no doubt impacted the study, particularly as the *WeInvestigate* unit drew to a close and she approached her retirement. At the time Ms. Jones' retirement was made public, the school switched to self-contained sixth grade classes, and experienced some initial challenges finding a full-time replacement for Ms. Jones. This series of transitions, the first of which – the move to self-contained classes - happened around the middle of the study, and the second of which – the transition between teachers – occurred during last two weeks of the study, and were fairly disruptive for students.  Additionally, the switch to self-containment prompted a few students, including one of the focal students, Marcel, to transfer to other schools (Omar took Marcel's place as a partner for Quentin).

The methods chosen for data collection and analysis in this study needed to enable us to examine student collaboration within, and potentially affected by, these complex, nested contexts in which this study took place.

**Overview of Methodology**

Given the purpose and social constructivist perspective of our study, qualitative and quantitative methods with an overall comparative case study approach (Merriam, 1998) were used. The study was conducted in one sixth-grade classroom, situated in a grade 2-6 Elementary School that has been struggling to address achievement gaps, in a small city in the Midwest.

The primary data collected for this study included transcripts of audio recordings, which documented pairs of students' face-to-face talk as they engaged in collaborative model construction and model-based explanation tasks within *WeInvestigate*. Screenshots of the collaborative artifacts produced by the pairs of students in the "collabrified" sections of the app, as well as students' independently written work done on paper, were also collected.  These data,

as well as supplemental data in the form of field notes, app log files, and pre-/post-assessments, were collected over the course of twelve lessons, spanning about four weeks. Data were sampled for transcription and analysis.

To provide some insight into the degree of collaboration, related specifically to students' transactive talk, and the content of students' discussion, quantitative content analysis (e.g., Chi, 1997) was conducted on all verbal representations of knowledge (via sampled transcripts) for the three student pairs. To more deeply characterize the collaborative knowledge building process, and whether/how it may have been supported by the collabrified technological learning environment, interaction analysis (Jordan & Henderson, 1995) was conducted on students' talk in conjunction with an analysis of their written artifacts, generated both independently and collaboratively. Chapter 2 of this dissertation provides the rationale for, and further describes, the methodological techniques used, with illustrative examples.

## Organization of the Dissertation

The overall research question, and larger study on student science learning and collaboration within the *WeInvestigate* app, led to the production of the three manuscripts presented in this dissertation, described below.

**Chapter 2 (Manuscript 1): Application of multiple methodological practices to study 6th graders' collaboration and knowledge building in a face-to-face and synchronous mobile digital learning environment**

Current reforms in science education (NGSS Lead States, 2013; NRC, 2012) have high expectations for what students should know and be able to do. Advances in technology are better able to support classroom instruction aimed at meeting these expectations. Both of these contribute to the increased complexity of studying the already very complex classroom learning

environment. This leads to the question: how can researchers measure and study what is occurring in increasingly complex, technology-integrated classroom learning environments? In order to understand what was taking place, and how it was taking place, within the unique *WeInvestigate* learning environment and the traditional school context in which the study took place, the use of multiple data sources and multiple analytical methods were necessary. To that end, the purpose of this paper was to provide guidance for how one could approach an analysis of "messy" classroom data collected for a study on student synchronous and face-to-face collaboration and knowledge building within a tablet-based learning environment. This paper elucidated many of the methodological decisions that were needed in order to conduct the study of student collaboration and knowledge building within the *WeInvestigate* learning environment. It also illustrated the application of the chosen quantitative and qualitative analytical approaches to selected data from the larger *WeInvestigate* study. Methodological implications for similar research on students' interactions within the context of CSCL and face-to-face learning environments within K-12 classrooms are discussed.

**Chapter 3 (Manuscript 2): *WeInvestigate*: The design of a tablet-based science app to support "collabrified" knowledge building**

As mobile technologies grow ever abundant in our society, more education contexts are investing in mobile technology, such as tablet-based apps, to support teaching and learning (e.g., Roscorla, 2010). However, few apps for education involve students in collaboration around the creation of content to support their learning through the app (Murray & Olcese, 2011). Therefore, the need for development of effective learning environments within these technological contexts increases, especially for our purposes as science educators, apps that can engage students in the kind of ambitious depiction of science instruction that is captured in current reform documents

such as the *K-12 Frameworks for Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The purpose of the work presented in the paper found in Chapter 3 was to elucidate the design rationale, and development, of a tablet-based synchronous science app called *WeInvestigate*, designed to support student science learning through collaborative engagement in science practices. Specifically, we describe our theory, or vision, of collaboration, and the design principles and features that were incorporated into *WeInvestigate* based on this vision, to support collaborative scientific modeling and model-based explanations.

**Chapter 4 (Manuscript 3): Investigating the "collabrified" use of an app to engage 6th grade students in model construction and model-based explanations**

The increased demands on students to master "21st-century skills," such as "technology-rich collaboration," as well as the three-dimensional learning laid out in NGSS (NGSS Lead States, 2013), have led, in part, to calls for the increased use of technology, specifically apps for mobile devices, to support ambitious teaching and learning in science classrooms. Synchronous, tablet-based learning environments, like the *WeInvestigate* app, provide opportunities to study the role that social interactions and collaboration around the creation of artifacts play in student learning, and the potential of such environments to support ambitious science teaching and learning in K-12 classrooms. The purpose of the paper in Chapter 4 was to report the findings of a pilot classroom study of students' synchronous and face-to-face collaboration as they engaged in constructing models and model-based explanations via *WeInvestigate*. We also hypothesize the impact the design principles described in Chapter 3 had on students' collaborative engagement in these science practices through the app. Lastly, we discuss the implications of this work for the future design and research of *WeInvestigate*, and similar educational technologies.

## Contributions To The Field

The findings from each of the papers in this dissertation are designed to contribute to the fields of science education, educational technology, and the learning sciences. The overall study captured in the three papers, was multifaceted, complex, and was unique in a number of ways. The synchronous nature of *WeInvestigate* across multiple features - videos, simulations, models, text – as well as the face-to-face aspect, distinguishes the technology itself. Further, this dissertation encompassed a study of the entire system of the integrated technology and lessons, which included student interactions with videos, text, modeling, simulations, and other students and the teacher. Additionally, the study was done in a naturalistic setting; that is, a traditional and fairly representative upper elementary science classroom in a challenging school district. This study provided some insight into several types of activities and tasks over time throughout a unit of study, via the combination of quantitative and in-depth qualitative methods.

Further, each paper detailed more specific contributions. Manuscript 1 provides methodological contributions via illustrations of how the use of multiple analytical quantitative and qualitative techniques can be used iteratively across multiple data sources to develop rich, descriptive cases of the nature of the collaborative knowledge building discourse that occurred for pairs of sixth grade students within a face-to-face and synchronous mobile digital learning environment. Manuscript 2 provides implications for developers of science curricula and technological learning environments through elucidating how the development of an innovative, research-based curricular context may be integrated and used in ever-advancing technological contexts to support student collaboration and knowledge building as they engage science practices. Findings presented in Manuscript 3 have the potential to contribute theoretically to our understanding of students' paired collaborative discourse via an innovative, research-based

curricular context integrated into a mobile app with the capability for synchronous collaboration across multiple features. The findings highlight the potential of the collabrified use of *WeInvestigate*, particularly WeModel, to support student engagement in some of the characteristics of effective collaboration. The findings also provide evidence that more support for collaboration, to more effectively utilize the collabrified modules, be built into the design of the learning environment, and suggestions for possible supports are made. Manuscript 3 may also contribute to the development of a theoretical collaboration "learning progression." Findings related to the teacher and implementation of *WeInvestigate*, not explicitly studied in this dissertation, are presented in Chapter 5, and have implications for teachers, teacher educators, and professional developers, by describing the importance of the teacher, challenges the teacher faces, and urging future studies on the role of the teacher in technological environments similar to *WeInvestigate*. Lastly, as a primarily qualitative study, some of the most valuable contributions are the hypotheses generated, including revisions to, and suggestions for, collaborative supports, which have implications for future technological designs and future studies of those designs.

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**CHAPTER II**

**Application of multiple methodological practices to study 6th graders' collaboration and knowledge building in a face-to-face and synchronous mobile digital learning environment**

**1. Introduction**

It has been hypothesized that the nature of student discourse centered on learning with technologies is an important indicator of the realizations of technology in classrooms (Bruce & Peyton, 1999).  To that end, computer supported collaborative learning (CSCL) environments provide opportunities to study both the role that social interactions and artifacts play in student learning, and the potential of such environments to support ambitious teaching and learning in K-12 classrooms. CSCL environments in K-12 classrooms may afford unique opportunities for students to engage in collaborative knowledge building because they allow learners to interact with visual representations, and construct representations of their thinking (e.g., Linn & Slotta, 2003), through a joint problem space (Roschelle, 1996), which may be built into the design of the learning environment. CSCL environments can also be designed to scaffold and guide student thinking through both synchronous, via the technology, and face-to-face (F2F) collaboration (Scardamalia & Bereiter, 2003).

However, researchers' increased access to multiple technological tools for designing CSCL environments to support collaborative learning presents a kind of mixed blessing. Technologies available for use in classrooms have become faster, more mobile, more affordable, and increasingly more comprehensive and capable of supporting social interactions. The design of intricate simulations and models, and real-time data collection via sensors housed both within

the mobile devices as well as probes attached externally with accompanying software make it possible for students to graph, analyze, and interpret complex data. At the same time, expectations for what students should know and be able to do by the time they graduate high school, as outlined in the Common Core State Standards (CCSS) (CCSSO/NGA, 2010) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), is becoming more demanding. This means that researchers interested in studying CSCL environments in our current technological and educational climate must design for and measure outcomes within more complicated learning environments. All of this raises the question of how to measure it all!

The complexity of CSCL environments presents methodological challenges for the study of these learning environments (Jeong, Hmelo-Silver & Yu, 2014). There are many possible modalities through which students can engage in technology-mediated collaborative learning. They may work as individuals, and collaboratively, with as little as one other person or as many as an entire class or school community. Their interactions may be face to face, or may be synchronous or asynchronous through computers or mobile devices. There are a variety of timescales over which interactions can occur, ranging from milliseconds to years. There are large amounts of interaction data generated during collaborative learning, and a variety of computer log data that capture who talks to whom and when. There are also a variety of individual and co-created digital artifacts. These data sources provide rich and plentiful information for deeply understanding students' collaborative knowledge building in CSCL environments, but the sheer volume and diversity of such data require multiple methodological approaches, each of which informs and reinforces the other (Schrire, 2006; Hmelo-Silver, 2003).

Chi (1997) talked about the need in educational research to collect and analyze "messy" data, (e.g., verbal transcripts, observations and video recordings, gestures) in order to study

complex activities in practice, in the context in which they occur. This same need still exists, and the "messiness" of classroom-based research increases when studying student interactions, collaborative artifacts, and knowledge building over time within a technological environment. To that end, the goal of this paper is to provide guidance for how one can approach an analysis of "messy" classroom data collected for a study on student synchronous and face-to-face collaboration and knowledge building within a tablet-based science learning app called *WeInvestigate*. This manuscript elucidates many of the methodological decisions that were needed in order to conduct the larger study of student collaboration within the learning environment, which is described in Chapters 3 and 4 (Manuscripts 2 and 3).

The *WeInvestigate* digital learning environment is an application ("app") for use on a tablet computer, designed to support students' collaborative engagement in learning science content and practices within a real-world context. In colloquial terms, it is a "fat app" - it is comprised of several applications, which are "collabrified" - WeModel (a drawing app), WeWrite (a text editor), WeRead (an ebook reader), WeWatch (a video player); furthermore, it plays simulations. Screenshots of these modules can be found in Chapter 3 (Manuscript 2). We use the term "collabrified" to mean that the app enables multiple students to work together synchronously, while each is on his/her own tablet (Soloway, personal communication, 2013). [See Chapter 3 for a complete description of this environment.]

It is important to note that the methodologies presented here are not new, and it is not the intent of this paper to position them as such. These have been used in the CSCL, learning sciences, and educational technology literatures for some time. The intent of this paper is to detail how the particular methodologies chosen can be used in one study of a complex and multifaceted technology-based learning environment. The data described in this paper, which

were not meant to be exhaustive, but illustrative, came from a larger research study for which the overall purpose was to investigate the tablet-based *WeInvestigate* science learning environment which integrates synchronous (face-to-face and through technology) student collaboration within a practice-based science curriculum, that was explicitly designed to leverage the unique features of an app for mobile devices. Specifically, the focus of this study was on one aspect of the environment, student collaboration, and how collaborative learning, supported by a model-based science curriculum that was designed to be integrated with and leverage specific functionalities of the technology, supported peer interactions, and facilitated knowledge building among pairs of sixth grade students. Because knowledge is built through social interactions and activities (Scardamalia and Bereiter, 1994; Vygotsky, 1978), in order to study collaborative learning between pairs of students, it was necessary to examine students' discourse as they engaged in collaborative learning tasks. The complex nature of student discourse as they engage in learning tasks through a unique digital environment necessitates the use of multiple methods to understand how knowledge is built through the discourse and engagement in the environment.

## 2. Methodological Approach

Given the purpose and sociocultural perspective of our study, qualitative and quantitative methods with an overall comparative case study approach (Merriam, 1998) were used. A case study design was chosen for its value examining meaning in context; thus, it is descriptive and interpretive in nature (Merriam, 1998). Case studies can be examined to bring about understanding, which can in turn affect, and hopefully improve practice in an applied field, such as education (Merriam, 2009). Knowledge gleaned from cases is driven and developed by reader interpretation in that readers bring their own knowledge and experiences to each case (Merriam,

1998).  Therefore, the cases were created, and cross-case analyses conducted to contribute new

knowledge to the field for readers to use in building their own generalizations.

Beyond this choice of overall methodological approach, a number of decisions had to be

made for the design of the study, including collection and analysis of data. These decisions are

detailed in the following sections.

## 2.1. School and District Context

We conducted our study in a traditionally underserved community school. The theory of

change for this study hypothesized that educational technology has the unique capability to

support student collaboration and knowledge building, and growth in conceptual understanding

by engaging in science-as-practice curriculum. We wanted to test the feasibility of this proposal

and the feasibility of using this kind of technology in a traditionally under-resourced school

using low-cost tablets. As the tablets in our study relied on wireless internet for the ability to be

collabrified (synchronously connected), we were also interested in testing the feasibility of the

internet infrastructure - deemed a challenge in many schools which educational technology must

overcome - of such a school (Education Research Center, 2011; Zhao et al., 2002).

The students included in this study were sixth grade students in a small city in the

Midwest.  This sixth grade was situated in a grade 2-6 Elementary School striving to address

achievement gaps. The school is both socio-economically and racially/ethnically diverse: 72% of

students are eligible for free or reduced lunch; the majority of students are from demographic

groups that have been underrepresented in the pursuit of STEM (63% of students are African

American, 23% White, 11% Hispanic, and less than 3% American Indian/Asian/Pacific Islander).

The school had seen a steady increase in the number of English Language Learners over the past

five years.  When compared to students across the State, the students in this school historically

underperformed on the State's standardized exams, across all categories. From June 2010-January 2012 the school experienced a turnover in building leadership three times. According to the school's 2013-2014 Strategic Improvement Plan, the "staff is undergoing a paradigm shift in regards to classroom instructional practices, school culture, behavioral plans, incorporation of technology into instruction, and project-based learning."

The summer before the school year in which our study took place, the district in which our study school was located merged with a neighboring, also under-resourced, school district under the guise of being better able to address economic and academic challenges. This consolidation of school districts contributed to upheaval in the school system, including teachers losing, then having to reapply for, their jobs. Our teacher-participant was subject to this process. The upheaval and disorganization of the resulting school district, in part, contributed to her making the decision to retire halfway through the school year, at the beginning of our study. Her decision to retire no doubt impacted our study, particularly as the *WeInvestigate* unit drew to a close and she approached her retirement.

## 2.2. Timing of study

A number of factors had to be considered when planning for classroom data collection. The amount of time it would take to complete the writing of the curriculum had to be considered, as well as the time it would take to share drafts of the curriculum with various people (e.g., a scientist and science educator), receive feedback, and revise. The amount of time it would take the programmers to develop various versions of the software also had to be considered, as well as how long it would take to conduct trial runs on the final app, and correct errors. School breaks, events, and the school's science scope and sequence had to be considered, as well as the teacher's own schedule; that is, when it was most convenient to participate in a research study.

For instance, the beginning of the school year was ruled out because the curriculum and app software were still in their planning stages. The beginning of the year was used as a time to meet with the teacher participant in order to plan the content and text requirements for the unit, while the programmers were developing the software. The end of the year was ruled out because of the many events and the time crunch that often occurs at the end of the school year. Enough time needed to be included for trial runs with the completed unit by the research team, with time to work out the kinks. It was decided the study would begin shortly after Christmas break. Data were collected during the months of January and February, 2014.

**2.3. Student participants**

Given our interest in deeply understanding the nature of students' interactions with each other as well as with the *WeInvestigate* app, and the nature of our study as exploratory and our mixed methods approach, a small sample of students were chosen by the teacher for data collection and analysis.

Ms. Jones[3], our teacher participant, identified six students from her class that would be the students of focus for this study: Mary, Hannah, Uma, Rose, Marcel[4], and Quentin[5]. She chose them based on their school attendance, reading levels, behavior, grades, and because they had prior experience collaborating with other students. She described the six original focal students as some of the best students in the class both academically and socially. They were also considered by Ms. Jones as some of the strongest readers in the sixth grade, a characteristic she felt might assist them in their more independent interactions with the *WeInvestigate* text.

It was decided that, for this study, the focal students would work in pairs because when students work in groups of two they engage in productive discourse more often than when

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[3] A pseudonym
[4] Halfway through the study, Marcel transferred to another school and was replaced by Omar.
[5] All pseudonyms

working in larger groups (Linn et al, 2003). Pairs of students also work to minimize the effect

often seen in larger groups of students of unequal engagement in the collaborative learning

activity, (O'Donnell, 1999).  Additionally, for the purposes of analysis, small groups exist at the

boundary of and mediate between an individual and the class.  The knowledge building that takes

place within pairs can become internalized as individual learning, and then can become

externalized in the larger class setting (Stahl, 2006; Webb, 1991, 1995; Webb & Palincsar, 1996).

Smaller groups also allow researchers to better observe the ways in which participants engage in

intersubjective learning (Stahl, 2006). The focal students were paired by the teacher in the

following groups: Mary and Hannah (group 1), Rose and Uma (group 2), and Marcel/Omar and

Quentin (group 3).

**2.4. Teacher participant**

The teacher in this study, Ms. Jones, was chosen because of her previous experience

working with the principal investigator in previous research and because of her position in a

struggling elementary school. Ms. Jones also represented a typical elementary teacher with

respect to her ease and comfort with technology. Because it was also important to understand the

context in which these students were learning, some data were collected with respect to the

teacher as well, specifically, an initial teacher interview and classroom observations prior to the

beginning of the study were conducted.  Classroom observations of teacher instruction were

made prior to instruction with the *WeInvestigate* learning environment. These observations, in

the form of field notes, represented baseline data about the classroom culture, student behaviors,

teacher instructional and managerial style; in addition, they documented how the teacher

scaffolded student collaboration.  An interview (documented via audio recorder) with the teacher

was also conducted to gather information about her science and teaching background, and her

instructional practices with respect to student collaboration, scientific modeling, and comfort with and use of technology.

Ms. Jones' classroom was very teacher-directed, structured, and textbook-based. It included few hands-on activities, very little student collaboration or technology use. As was mentioned previously, Ms. Jones had decided to retire at the beginning of the study. Though her official retirement began during implementation, she returned to school each day to teach the study class one period a day.

## 2.5. Data sources

Also in keeping with the purpose of our study, and our choice of methods, the primary data collected for this study included transcripts of audio recordings, which documented pairs of students' face-to-face talk as they engaged in collaborative learning tasks within *WeInvestigate*. Knowledge building requires the creation of "epistemic artifacts" defined as tools that serve to advance knowledge (StereIny, 2005). Epistemic artifacts may be conceptual (e.g., theories and abstract models) or they may be concrete (e.g., models and experimental setups). Because knowledge begets knowledge, artifacts created during knowledge advancement are important educational tools that support the creation of new knowledge (Blumenfeld et al., 1991). Therefore, screenshots of the collaborative artifacts created by the pairs of students in the "collabrified" sections of the app, as well as students' independently written work done on paper, were also collected. Some examples of the types of student artifacts collected (both individual and collabrified) included: initial models, revised models, model-based explanations, and answers to in-text question prompts.

Though most of what happened in the classroom was captured by the audio recordings, field notes were collected by research team members while observing the three focal pairs of

students.  Field notes documented, with timestamps, the activities of the lesson, including modifications to the lesson-as-written, such as when the teacher chose to perform a demonstration not found in the curriculum, or when there were unforeseen delays such as classroom visitors.  Field notes also documented focal students' actions not captured by audio recorders, such as when a student looked to the text in WeRead while answering a question in WeWrite, or when students were working independently on a task that should have been done collaboratively.

A sixteen-item content knowledge measure was developed by the *WeInvestigate* project team and given to the entire class immediately prior to and immediately following instruction with the *WeInvestigate* learning environment.  Items were adapted from existing, validated tests (e.g., TIMSS, AAAS, NAEP), and were aligned with the content of the *WeInvestigate* curriculum.  Because the curriculum was designed for alignment with state standards and NGSS, the assessment items also align with those standards.  The assessment included items that primarily measured student knowledge of the science content. Administering the same set of items in both the pre- and post-assessments allowed for comparison of students' knowledge before and after instruction with *WeInvestigate*, and for some additional insight into how students' knowledge developed over time. The items included forced choice, as well as open-ended responses that would inform our understanding of how students' modeling at the molecular level had changed over the course of the instruction.

Log files documented student actions while working in the collabrified features of the app (WeModel, WeWrite, and WeWatch).  The information found in logs was linked to students' talk; for instance, when students communicated with each other about which numbered session to join, or when a student cleared the entire model from the screen. This information was also

used as a rough measure of "equality" of participation in the collaborative artifact being produced.

## 2.6. Data sampling

Due to the volume and complexity of the data collected, purposeful sampling was done in preparation for analysis. Data were initially chosen for analysis primarily based on the nature of the activities of the lesson, as well as the research team's general sense of how successful that lesson's enactment was. For example, Lesson Six was chosen both because it included a modeling task (students engaged with a simulation), and because the research team felt the students were engaged in this lesson and were able to use the guidance found in *WeInvestigate* to successfully progress through the lesson mostly independently. Lessons that did not include modeling tasks were not included in the sample.

Data were also sampled relatively evenly in time across the duration of the twelve-lesson (five week) implementation. More lessons were sampled from later in the unit, mostly due to students' comfort with using the technology, and teacher's comfort with the new [for her] instructional style necessary to utilize the tablet-based learning environment. Due to the nature of the technology used in this study - including the audio recorders in addition to the tablets - there were missing data. Sampling, therefore, was also dependent on finding lessons with complete data for all focal students.

Lessons were also sampled to ensure a diversity of types of modeling activities, and to include opportunities for both individual and collaborative work. For instance, students created models to explain how each change of state could occur at a molecular level. This was done across five lessons. Three of these five lessons (for evaporation, melting, and sublimation) were chosen for analysis. Lessons that included opportunities for students to interact with

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professionally designed models, such as computer simulations, were also chosen for analysis, as were lessons that included some pre-activity independent work and think time, as well as post-activity independent follow-up work, in addition to the collaborative work that comprised the bulk of each lesson.

## 2.7. Preparing the data

Face-to-face discussions between the focal pairs of students were collected via audio recorders for all twelve *WeInvestigate* lessons, lasting between 60 and 90 minutes each.  In order to transform the verbal data into written text for analysis, a sample of the audio recordings, described in the previous section, for each group were professionally transcribed. Transcription was done for student utterances.  An "utterance" was defined as "a distinct message from one student to another student or to him- or herself" (Gijlers &  de Jong, 2009, p.252), and was distinguished in the transcripts as a turn of talk. In other words, a new utterance was identified when the speaker changed. When there was no speaker for more than 10 seconds, a new utterance was transcribed, even if the next speaker was the same student who had last spoken before the break.

The lead researcher then prepared the transcripts for coding by comparing them to the audio files, and making corrections to the transcription as necessary. Transcripts were also broken up into episodes (Lemke, 1990) based on lesson task and lesson structure.  For example, it was noted when students were working with their partner to complete a modeling task versus when they were sitting more or less silently during a teacher-centered whole class "discussion." Consistency between the length of episodes across groups was maintained based on identifying remarks in the teacher's talk, usually signifying the end of a lesson task and the beginning of the next task. Finally, relevant excerpts were taken from the field notes and added to the transcripts

to provide more context. For example, when available, notes were added to the transcripts that communicated student gestures or eye placement, such as when both students were looking at a single tablet. Once the transcripts were fully reviewed and amended they were uploaded to a web-based qualitative coding and analysis program called Dedoose.

## 2.8. Coding tools

Dedoose was chosen as the coding program primarily because it is a web-based coding environment, with all data and analyses saved automatically in the cloud, rather than locally on a personal computer. This helped avoid issues associated with "version creep," and backup and storage. Dedoose also has easy collaboration capabilities, and a variety of data display options to assist researchers in immediate and ongoing visualization of their data. Dedoose also offers many choices with respect to exporting coding data to external programs, such as Excel. Although Dedoose does have powerful data visualization capabilities, further analysis and data visualization was done in Excel, for its increased control over the data, and functionality over Dedoose.

## 3. Analytical technique: Quantitative content analysis

With the above decisions made, and the transcripts prepared, coding and analysis were begun. In order to gain an overall sense of the data and begin to identify patterns and themes, we began with quantitative content analysis. Quantitative content analysis (e.g., Chi, 1997), a "code and count" method commonly used in CSCL studies (Jeong, Hmelo-Silver, Yu, 2014; Suthers, 2006), was conducted on all verbal (via transcripts) representations of knowledge for the six students (three pairs). Content analysis has been demonstrated as a useful method for studying both computer-mediated and face-to-face communication (e.g., Hara, Bonk, & Angeli, 2000; Henri, 1992). Content analysis is often referred to as a quantitative-based qualitative approach.

It is a "methodology for quantifying the subjective or qualitative coding of the contents of verbal utterances" (Chi, 1997, p.2). The quantifying of qualitative coding is done by tabulating, counting, then drawing relations between the different types of utterances, meant to reduce the subjectivity of the analysis. Content analysis seeks to remove subjectivity and align itself more with quantitative analysis, while still maintaining the richness of the data collected. Because of the methodological focus of this paper, the findings and discussion presented throughout were purposefully confined to a limited aspect of the larger study - the transactive nature of student talk.

## 3.1. Grain size for content analysis

To perform the coding for the quantitative content analysis, the unit of analysis, which refers to the basic unit of text to be classified, first needed to be determined. There should be a correspondence between the research question(s) guiding a study and the grain size of analysis (Chi, 1997). Therefore, given our focus on the discursive nature of the text being coded, and in line with previous analyses of student interaction (e.g., Roschelle, 1992), we chose the grain size for coding to be the utterance level. Mentioned previously in the section on preparing the data, audio recordings of students' talk were transcribed at the utterance level, with an utterance defined as a turn of talk in the transcripts. While the students were working with their partners to complete lesson tasks, every utterance of student talk was coded according to the coding framework described in the following section.

## 3.2. Coding framework for content analysis

The content analysis provided some initial insight into the type and extent of transactivity of students' discourse, considered a key component of student collaboration (Noroozi et al., 2012; Weinberger and Fischer 2006; Teasley, 1997). Transactivity has been defined as the extent to

which learners take up and negotiate the reasoning of their peers (Teasley, 1997). Utterances in which students integrate their partners' ideas in their own reasoning, or critically discuss their partners' contribution, are considered highly transactive and are associated with positive learning outcomes (Teasley, 1997). There are indications that the more transactive the student discourse, the more students individually benefit from collaboration with peers (Teasley, 1997). Each student utterance was first characterized as "on task" or "off task" communication. Off-task communication was defined as any communication not related to the task as it was defined in the instruction. All utterances characterized as off-task did not undergo further coding or qualitative analysis, as described below. The amount (percentage) of total on-task discourse, which has been found to be positively related to individual knowledge acquisition (Cohen, 1994), was determined.

A pre-validated coding framework, used in several studies of student discourse, was used. On-task utterances from transcribed dialogue were further coded according to several dimensions found in the validated frameworks from Weinberger and Fischer (2006), Gijlers and de Jong (2009), and Gijlers et al., (2013). In addition to the use of a scheme derived from these frameworks, transcripts were analyzed with some degree of inductive, or grounded, coding. Inductive codes arose from a need to characterize student utterances in ways that were not encompassed by the original coding framework. For the purposes of this paper, a sample of the coding framework, focused on the transactivity codes, is included in Table 2.1. The entire coding framework, which was developed through iterative coding cycles (same lesson across groups and multiple lessons for the same group) (Miles & Huberman, 1994; Strauss & Corbin, 1990) can be found in Appendix 2.A.

Table 2.1.

*Coding Framework Sample*

| CODE | DESCRIPTION/RULES | EXAMPLES FROM THE DATA |
|---|---|---|
| Externalization | Applied to student utterances that were considered new contributions to the discourse with respect to content-related talk. Externalization was only applied the first time a student said something; a unique utterance. The exception to this rule was when the student was speaking to a new person, e.g., when a teacher came over to check in, or if the student repeated what they had already said, but then added more onto it. This is because externalizing their knowledge to a new person gives that person a chance to respond to that knowledge, thus opening up the possibility for more, new knowledge to be shared. Apply code for a contribution to the original idea (when it does not fit as another form of transactive talk). This most often happens when a student builds on his/her own initial idea, even if the utterance is several utterances later. (Noroozi et al., 2012). Because Elicitation leads to others externalizing their ideas, the utterance following a partner's (or teacher's or text's) elicitation is coded as externalization if it is a response to that elicitation. | Rose: Can I write it? [elicitation] Uma: Okay. We should make the water brown. I don't know why. I just feel that. [externalization] ——— Uma: Yeah. What did you observe happen in the simulation? [question from text] Rose : It went really slow, it went really fast, and it went medium. [externalization] |
| Elicitation | Apply this code when students question their partner to receive additional information. Typically, elicitation is a question, but can also comprise requests for feedback that demand an affirmative or a negative response from a partner. Elicitation is coded for all questions asked. If the partner does not respond to the elicitation it receives the No Reaction code. | |
| Quick consensus building | Apply this code when students simply agree or disagree with the ideas their partner contributed, without further elaboration or critiquing. An utterance with this code will usually follow an externalization utterance. This code does not apply when a student is just answering yes/no to a question. The exception to this rule would be when the student is eliciting a response from another student that really is more of a statement, and are looking for agreement because they finish with "Right?" (i.e., look for instances of agreement/disagreement, vs. when a student is asking/answering yes or no). | Mary: Yep. Draw the line. No. No, no, no. It's liquid. You have to draw the line cuz it's a liquid. It sits in a puddle. [externalization] Hannah: Oh, okay. I didn't know it was in that. [quick consensus] |
| Integration-oriented consensus building | Apply this code when students build on the ideas of a partner, integrate multiple ideas or viewpoints, or take over the perspective of a partner. An utterance with this code will usually follow an externalization utterance. Integration consensus can also be applied when one student is typing and speaking aloud while doing so, and the other student is adding to their words. The exception to this rule is when a student is simply reading over what has been typed without adding anything to it. | Hannah: Okay. The motion. The motion. The high temperature affected cuz if you pour hot water into something it goes [sound effects] like fireworks off. [externalization] Mary: When you heat up water it boils and then it turns into water vapor. [integration consensus] |

| Conflict-oriented consensus building | Apply this code when students do not accept the contributions of their learning partners as they are. They operate on their partner's reasoning by critiquing and modifying their contributions or presenting them with alternatives. An utterance with this code will usually follow an externalization utterance. | Mary: Then, number four is a liquid gas. [externalization] Hannah: No. It's a gas or a liquid cuz condensation is that, or you could continue. Some steam comes up, and it goes to the window and saw water. [conflict consensus] |
|---|---|---|
| No Reaction | When learners did not respond to elicitations and externalizations from their learning partners, we coded the chronologically next message as "no reaction" (Noroozi et al., 2012). Even if the utterance immediately following an elicitation or externalization is coded Off-Task, still code that No Reaction. | Marcel: What evidence from your experiment do you have to support this? [elicitation] Quentin: Just looking at the pictures. [no reaction] |

## 3.3. Representing the data – Data "slices"

Quantitative content analysis (Chi, 1997) was used in this study to gain an initial understanding of the nature of the data, as well as to indicate the lessons and lesson tasks where more detailed qualitative analyses should be focused. The volume and complexity of the coded content analysis data necessitated different views and "slices" of the data, to better visualize the data and to ensure that valid conclusions could be drawn.

**3.3.1. Slice 1: Transactive talk of all sampled lessons (compiled).** The first slice of the data included coded utterances across all sampled lessons, and provided a "broad strokes" perspective. At this level, the data were displayed in several ways. First, shown in Table 2.2, an overview of the on-task talk for the transactive talk codes for all sampled lessons is presented. At this level we already see differences with respect to the groups, as well as the talk codes. Group 1 had more total utterances (i.e., they talked the most) than the other two groups, but they also had the highest percentage of off-task talk. Group 2 had the most on-task talk. Students more often engaged in lower level transactive talk, particularly externalization and elicitation, and higher level transactive talk was rare. Group 2 had the lowest percentage of no reaction, and highest percentage of high-level transactivity, while Group 1 had the highest percentage of no reaction and lowest percentage of low-level transactivity.

These overall findings provided some early indication of notable similarities and differences between the groups. For instance, the fact that the "no reaction" code was low across all the groups meant that when a student attempted to elicit a response of some kind from their partner, they did receive it. Additionally, in our study we conceptualized stronger, or potentially more productive collaborative knowledge building discourse as discourse in which students were engaged with each other (i.e., responding to one another), and with higher levels of transactivity (e.g., Teasley, 1997). Therefore, it may be deduced from this information that, in general, Group 2 may have had stronger collaborative knowledge building discourse than Group 1.

Table 2.2.

*Code frequencies and percentages for on-task transactive talk for all sampled lessons.*

|  | Group 1 | | Group 2 | | Group 3 | |
|---|---|---|---|---|---|---|
| *Total utterances* | *2216* | | *1973* | | *1446* | |
| *Total on-task utterances* | *1606* | | *1814* | | *1256* | |
| *% on task* | *72.47* | | *91.94* | | *86.86* | |
| **Codes** | **Freq** | **% on-task** | **Freq** | **% on-task** | **Freq** | **% on-task** |
| Externalization | 278 | 17.31 | 262 | 14.44 | 187 | 14.89 |
| Elicitation | 281 | 17.50 | 265 | 14.61 | 218 | 17.36 |
| Quick Consensus | 174 | 10.83 | 266 | 14.66 | 99 | 7.88 |
| *Total Low-Level Trans.* | *733* | *45.64* | *793* | *43.72* | *504* | *40.13* |
| Integration Consensus | 45 | 2.80 | 61 | 3.36 | 33 | 2.63 |
| Conflict Consensus | 16 | 1.00 | 53 | 2.92 | 17 | 1.35 |
| *Total High-Level Trans.* | *61* | *3.80* | *114* | *6.28* | *50* | *3.98* |
| No reaction | 52 | 3.24 | 24 | 1.32 | 37 | 2.95 |

**3.3.2. Slice 2: Across-lesson view.** The second slice of the data examined the transactive talk for each group for each sampled lesson. Similar tables to Table 2.2 were generated for each sampled lesson, but altogether these tables, even if placed in one large table, took up too much space, and patterns in the data were less easily spotted. Instead, a graphical representation was generated, which allowed for ease of visualization of the data; specifically, the graph allowed us to see the data simultaneously across all sampled lessons, shown in Figure 2.1. This allowed us

to see if any notable patterns existed or changes occurred in the data over time. This view also allowed us to begin to ascertain which lessons might be fruitful for qualitative exploration.



**On-task transactive talk per group per lesson**

Legend:
- No reaction
- Conflict Consensus
- Integration Consensus
- Quick Consensus
- Elicitation
- Externalization
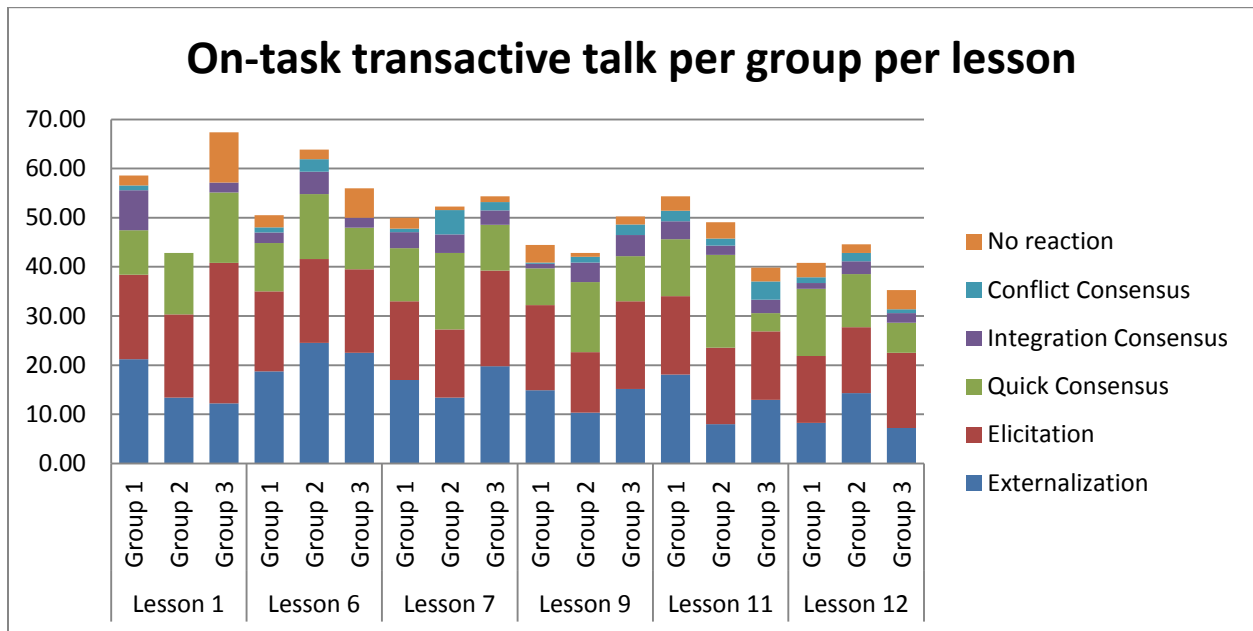
*Figure 2.1.* Total percent of the on-task transactive talk codes per group per sampled lesson.

The view of the talk codes per group per lesson shown in Figure 2.1 supports the data shown in Table 2.2, for instance, that higher level transactive talk (conflict and integration consensus) was rare for each group across all lessons. Still, at this level of data visualization, more nuance arises. For instance, in Table 2.2 we saw that Group 2 engaged in more high-level transactive talk, and Group 1 engaged in less high-level transactive talk, than the other two groups. However, the representation in Figure 2.1 shows that, for instance, in Lesson 1, Group 2 did not engage in any high level transactive talk, while Group 1 did, and in fact engaged in quite a bit (relatively speaking) of integration consensus talk. New patterns also emerged with this view of the data. For instance, in general, each group seemed to externalize slightly more often earlier in the unit than later. In general, the amount of high-level transactive talk seemed fairly consistent (and consistently low) across the unit. In general, at this level, there is a great deal of variation across the lessons with respect to the talk engaged in by each group, with none of the

groups really standing out as engaging consistently more or consistently less in any one kind of transactive talk than the other groups.

As a result of this level of analysis, and taking into consideration what we knew the lessons to be about, we considered Lessons 1 and 12 for further analysis, because of the differences in the talk that occurred over time; specifically, there seemed to be more transactive talk in Lesson 1 at the beginning of the unit than in Lesson 12, at the end of the unit. We had been tempted to predict that as a result of students' interactions with and via *WeInvestigate* we might see more high-level transactive talk later in the unit, but this was not shown to be the case. Therefore, we felt a comparison of these two lessons, which also "bookended" the unit nicely, given that the lessons were essentially the same, would provide some insight into why we did not see more high-level transactive talk. We also knew we would sample lessons from the middle of the unit as well for comparison. The [relatively] higher amounts of high-level transactive talk observed in Lessons 7 and 9 included these lessons as possibilities. The stark differences in the talk among the three groups in Lessons 6 and 11, however, also meant these might prove fruitful for further examination as well. Given our original sampling criteria (described previously) we also wanted to examine patterns in the different kinds of tasks in which students engaged throughout the unit to determine not only which lessons - but which tasks within those lessons - we might want to analyze more deeply.

**3.3.3. Slice 3: Lesson task view.** Another way to examine all of the sampled data was by lesson task. After transcription was completed but before coding, the lessons had been chunked by lesson task. This was done so that the collaborative discourse could be examined for patterns not just with respect to different lessons, but different types of tasks associated with the different *WeInvestigate* app modules so that claims could potentially be made about how students engaged

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with the different modules. The lesson tasks included times when students were using WeWatch to view videos, using WeModel to construct their own models or to interact with computer simulations, or using WeWrite to write explanations, and answer follow-up questions. The graph shown in Figure 2.2 shows the patterns in data across lesson tasks.

## On-task transactive talk codes per group per lesson task
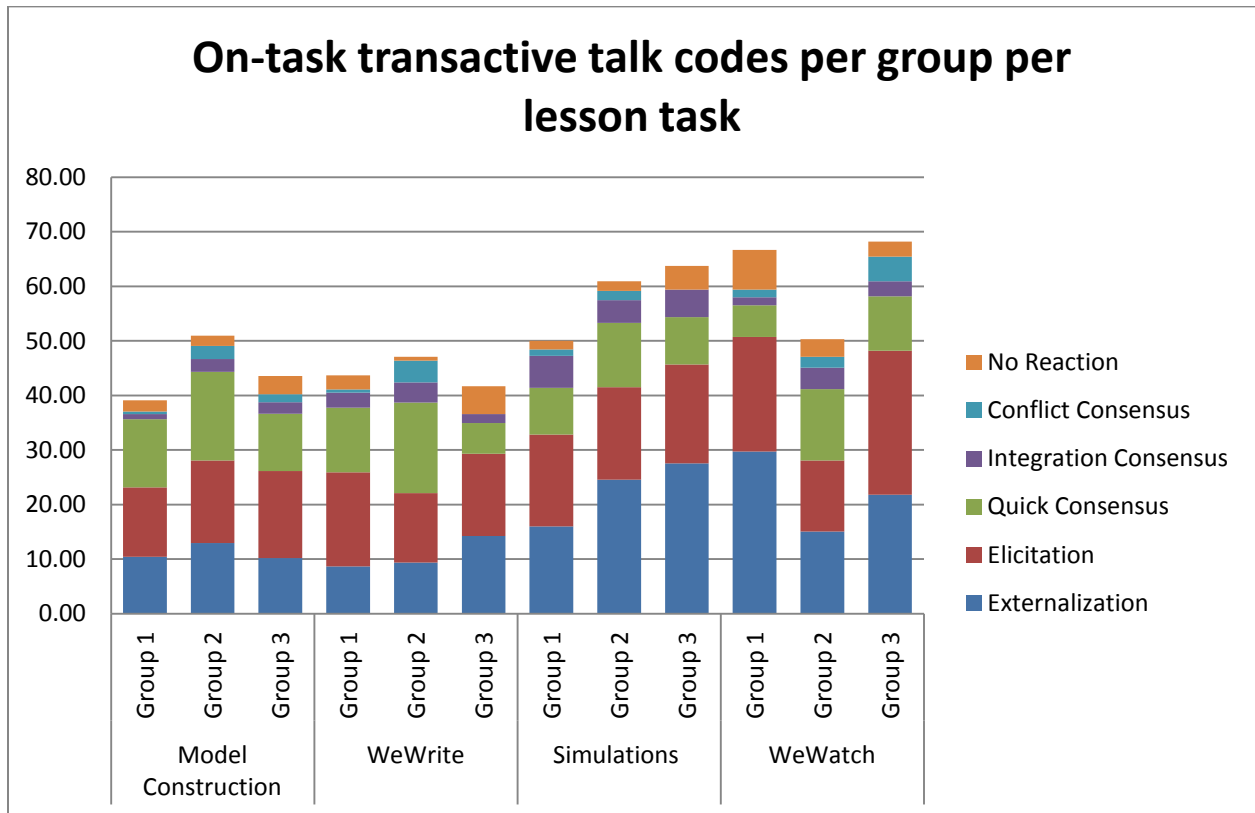
*Figure 2.2.* Total percent of the on-task transactive talk codes per group per type of task.

Examination of Figure 2.2 reinforces findings from Figure 2.1 and Table 2.2; namely, high-level transactive talk is rare across the different tasks. In this view we also see that the groups engaged in more integration consensus during simulation tasks and more conflict consensus during WeWatch tasks. Visualizing the talk by task rather than by lesson shows that the groups generally asked each other more questions and externalized more as they watched videos and interacted with simulations. Also, the groups generally engaged in less high-level transactive talk during model construction tasks than the other tasks. During model construction

tasks students were generally more engaged in attaining quick consensus than they were during other kinds of tasks. Given that the students produced artifacts during model construction and WeWrite tasks, but not during simulation and WeWatch tasks, these findings perhaps become more telling of what may have been occurring during lessons. For instance, students shared fewer explicit content-based ideas (externalizations) when they were producing something than when they were mostly observing. The fact that the students generally engaged in more quick consensus and, with some exception, generally did not engage in higher-level transactive talk during model construction and WeWrite tasks, means that they may not have been engaged in much collaborative knowledge building through the production of artifacts, and they may instead have been more focused on task completion.

With this more revealing slice of the data, we knew we would focus our qualitative analysis efforts on model construction tasks and WeWrite tasks to better understand how students were interacting with each other, including the content of their discussions, as they were co-constructing artifacts. Lessons 7, 9 and 11 (in addition to Lessons 1 and 12, which we had already chosen for qualitative analysis) all included both model construction and WeWrite tasks. Given the combination of findings from Figures 2.1 and 2.2, as well as our knowledge of what occurred in these lessons, we chose Lesson 7 for further analysis. Additionally, given the findings shown in Figure 2.2 for another kind of modeling task, the simulations, we decided to further analyze Lesson 6 as well. Lesson 6, which Figure 2.1 reveals included more externalization than other lessons, as well as a fair amount of high-level transactive talk, and variation between the groups, would present a nice comparison with Lesson 7. Although we had decided to qualitatively analyze Lessons 1, 6, 7, and 12, we continued to graphically explore the

tasks across our chosen lessons for patterns in students' transactive talk. For the remainder of the paper, illustrative findings from Lesson 7 will be discussed.

## 4. Analytical technique: Interaction analysis

Data analysis in many computer supported collaborative learning (CSCL) environment studies such as this one, is often done by coding and counting frequencies (Suthers, 2006), as described above. This method is useful for initial characterization of the data, as well as for indicating where more detailed analyses would be merited (Suthers, 2006). Although the "coding and counting" method of content analysis was helpful for getting an overall picture of the data, and for determining relevant episodes for which to conduct micro-analyses, other methods, for explaining and interpreting the interactions that occurred with and through jointly-created and technologically-based products of learning, were needed. Based on findings from the quantitative content analysis, as well as a consideration for the types of tasks we were interested in characterizing, specific lessons and lesson tasks were chosen for in-depth qualitative analysis of students' talk in conjunction with the artifacts they produced.

There is little precedent in the literature for the analysis of written, collaboratively-created technology-based artifacts, in conjunction with the simultaneous student discourse that occurred around the generation of those artifacts. Looi and Chen (2010) adopted a framework of interaction analysis (Jordan & Henderson, 1995) using concepts from uptake analysis (Suthers et al., 2007) for their study, which explored the process of knowledge convergence and knowledge sharing through face-to-face discussions mediated by a shared technological representational generic workspace (Group Scribbles). Because the nature of our study was similar to that of Looi and Chen (2010), interaction analysis was also undertaken to more deeply characterize students' collaborative knowledge building discourse.

Interaction analysis is a method for the empirical investigation of human interactions with each other and their environment (Jordan & Henderson, 1995). It investigates human activities, such as talk, and the use of artifacts and technologies. Researchers employing interaction analysis consider the construction and manipulation of representations within a shared workspace, which may or may not be supplemented by face-to-face interactions. Participants collaboratively build knowledge through negotiation and sharing of their ideas around the co-construction of external representations of their knowledge, providing the basis for the group or pair's intersubjective meaning-making (Suthers, 2006). The goal of interaction analysis is to identify patterns in the ways in which participants engage in knowledge building through interactions around external knowledge representations (Jordan & Henderson, 1995). To do this, talk and interaction between people are analyzed sequentially, that is, each utterance is viewed in relation to the previous utterance within a selected episode. In this study, an utterance-by-utterance interaction analysis was conducted for on-task utterances within sampled lesson tasks.

The interaction analysis of student talk did not just occur between the students in each pair. Students' co-constructed artifacts were also analyzed relative to the student discourse that occurred around the generation of those artifacts to determine student-artifact interactions, more specifically, the degree to which the production of the artifact mediated, that is made possible and guided (Suthers, 2005), student collaborative knowledge building discourse. In order to do this, individual contributions by each student to the artifact were considered, as well as whether an individual's suggested contribution was acted upon – that is, whether the partner agreed to it "as is" or modified or amended it in some way - by a partner prior to being included in the artifact. The relative contributions of the students in each pair, and whether contributions could be considered individualistic (accepted "as is" by a partner) or collaborative (acted upon by a

partner), were examined. The log files served as a check, or to reinforce what analysis of the verbal discourse was showing about how equivalent the participation in the production of the final product was. Taken together, these analyses of student discourse in conjunction with the artifacts, supplemented as needed by log files (when available), provided some determination of whether the discourse indicated collaborative knowledge building discourse using *WeInvestigate*. The following example from the case of Mary and Hannah provides an illustration of how interaction analysis was done in conjunction with a jointly-created student artifact.

**4.1. Mary and Hannah: Using interaction analysis in conjunction with analysis of jointly-created student artifacts**

Based on previous research, we identified characteristics considered to be identifiers of productive collaboration, which we looked for during our analysis of students' interactions. In addition to higher-levels of transactive talk (i.e., consensus-building talk), we looked for evidence (or absence) of acknowledgement from a partner (Dabbagh, 2005; Barron, 2003); joint attention by both students in a pair (Barron, 2003) to a shared representation (Suthers, 2005; Schwartz, 1995); and ways in which the artifact being created mediated (Suthers, 2005) student discourse. As described previously, similar to how coding proceeded for the content analysis, the interaction analysis proceeded utterance-by-utterance in order to examine each utterance in relation to the previous utterance. Transactive talk codes applied to each utterance are included in the example shown in Excerpt 2.1 for reference, as these codes were considered in the interaction analysis.

Prior to the discourse shown in Excerpt 2.1, Hannah had been doing the drawing in WeModel while Mary monitored and provided instruction and feedback. However, because WeModel supported synchronous work, the girls began drawing simultaneously, deciding to split

up the drawing task. Their teacher had given them a template to support them in constructing their model of evaporation. The template consisted simply of four boxes in which the first box was meant to show the initial state of matter, and the last box was meant to show the final state of matter in the evaporative process, while the inner two boxes were meant to represent transitional "states." Hannah decided she would draw the outer two boxes, while Mary would draw the inner boxes. Because they split the task, they at first drew in their own part of the model more or less independently of one another. As Hannah drew her part of the model, she externalized an idea about what she was drawing (U297), but was interrupted by Mary, who was preoccupied with the portion of the model she was responsible for drawing, as she sought to elicit Hannah's opinion rather than react to what she had been saying (U298). In other words, at this point, although they were technically engaged with a representation shared between both of them, each girl's attention was focused on her own part of the model only, and were not necessarily engaged in collaborative knowledge building discourse.

*Excerpt 2.1*

| | | |
|---|---|---|
| 1-7-U297 | Hannah: Gas fills its container, so I don't have to like— | *Externalization* |
| 1-7-U298 | Mary: Well, should the line go away on the second one cuz it's evaporating, or should some go outside the line and then the line goes with the second one? | *Elicitation, No reaction* |
| 1-7-U299 | Hannah: What are you talking about? | *Elicitation* |
| 1-7-U300 | Mary: You see the line that's liquid. Then, should the line still be there? Then, I'll make some up above the line cuz the liquid was still there. | *Externalization* |
| 1-7-U301 | Hannah: Yeah. Yeah. | *Quick Consensus* |
| 1-7-U302 | Mary: Okay. Then, the line just goes like—but it's not filled up yet, or just keep the line. | *Elicitation* |
| 1-7-U303 | Hannah: Well—- like this. | *[?]* |
| 1-7-U304 | Mary: No. Then, just fill the container. | *Conflict consensus* |
| 1-7-U305 | Hannah: Yeah. No. Not fill it up like—then, it goes to my picture. No. Wait. You gotta erase some of that. […] | *Conflict consensus* |

As a result of Mary's interruption, Hannah was momentarily confused, as judged by her response (U299). This shift in Hannah's attention from her own drawing to Mary's, in response to Mary's interruption, led to more transactive talk between them as they both became jointly attentive to Mary's portion of the model. In response to Hannah's elicitation, Mary rephrased and clarified her thinking, making reference to the model through her use of "there" (U300). In clarifying her question for Hannah, Mary actually decided what to do, thus also externalizing a suggested contribution to the model (U300), with which Hannah agreed (U301). With one part of her drawing completed, Mary continued with another proposed contribution, in the form of an elicitation to Hannah, again making reference to the model, "line just goes like—" (U302). Hannah responded with an alternative suggestion by drawing to show, instead of say, to Mary what she should do (U303). Mary disagreed with Hannah's drawn suggestion, and proposed another suggestion (U304). Hannah then disagreed with Mary's new suggestion, providing some reasoning for why, using her part of their model as a reference (U305). Although Mary and Hannah began this excerpt preoccupied with their designated piece of the model, by the end they had engaged in a brief negotiation to come to consensus on a plan for drawing their boxes in a way that made sense individually for each box, and which also showed a logical progression from Hannah's part of the model to Mary's part and back to Hannah's part.
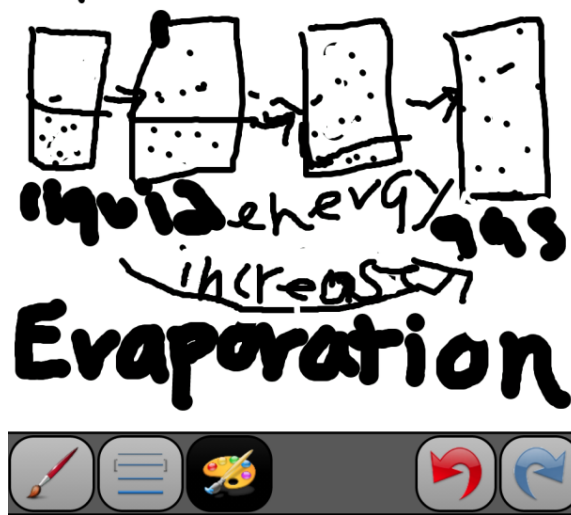
*Figure 2.3.* Mary and Hannah's final bromine evaporation model.

While this utterance by utterance analysis took place, Mary and Hannah's final model, shown in Figure 2.3, was at hand both as a reference, and as part of the analysis by answering the following questions: Did the model include the suggested contributions of the students from Excerpt 2.1? Were the suggested contributions taken up "as is" or were they modified in some way? For example, did Hannah's gas "stage" representation show the gas filling the container (U297)? Did the second "stage," drawn by Mary, show a liquid line with some molecules above the line (U300)? Did the third "stage," also drawn by Mary, show some difference between the second stage, but not filling up the box yet, so that it could transition to Hannah's final stage (U305)? The answer to all of these questions was "yes" so that both Mary and Hannah's suggested contributions, with some modification, were included. Through this kind of analysis, that is, through an examination of the discourse in conjunction with the student artifact produced during that discourse, it was determined that the discourse that took place around the construction of this part of the model represented collaborative knowledge building discourse because it resulted in the sharing of multiple, and some collaboratively-generated, contributions

to the final product, the students engaged in some high-level transactive talk, they had joint attention to a shared representation, their model, which seemed to mediate their talk in that it was the reason for the talk, changed with the talk, and was even used as part of the talk (U303).

From the results of the content analysis we knew that some transactive talk occurred during the bromine evaporation model task in Lesson 7 (the "what" and the "when" of the student talk), but as a result of the more fine-grained interaction analysis, we were able to describe *how* this kind of collaborative discourse occurred. After her initial interruption, Mary's uncertainty and continual questioning (U300, U302) worked to advance the discussion, until she felt satisfied she received the help/advice she needed.  What also advanced the discussion was disagreement between the students (U303, U304, U305), which necessitated further explanation (Kuhn, 2015; Schwarz et al., 2000). In both instances, Mary and Hannah referenced the model or drew in the model to demonstrate or support their thinking. In this way, the analysis revealed how the collabrified nature of WeModel seemed to support the students' use of their model as a mediator for their thinking and talk (Roschelle, 1994).  Mary externalized a thought and drew to illustrate her thinking (U298, U300, U302). While she did so, Hannah observed on her own tablet and provided immediate feedback, disagreement, which simultaneously included her drawing to illustrate her thinking (U303, U305).

A couple of methodological concerns arose as a result of this analysis. Given our purpose to study whether and how students were able to collaborate and learn within a complex technological environment, we needed information about students' interactions with each other, but also documentation of their interactions with the artifacts they produced. We sought to examine and understand the process, and not just conduct a pre-/post-type of analysis.

Therefore, one challenge that arose was that the artifact produced, such as the one shown in Figure 2.3, was the final product. We know from students' talk and the log files that there was quite a bit of work, and several versions of the model prior to this one. Although in most cases we had evidence to make some strong assumptions about the degree to which each student's suggested contributions ended up in their final product, we could not know with certainty what was drawn during students' conversations, or who drew it.

Another challenge that arose during this study, specifically, after the content analysis had been completed, and during the interaction analysis, was a discrepancy between what had been coded and counted based on the utterances alone, versus what was uncovered via consideration of the utterance context, as well as what the students were actually doing at the time of the utterance. Interaction analysis revealed, such as in the case of Mary and Hannah, that some of the interaction between the students occurred through and was mediated by the joint artifact. However, the "talk" that occurred less explicitly through the model drawing, for instance, was often not considered according to the coding framework used, unless it represented an explicit instance of that kind of talk. For example, Hannah's utterance in Excerpt 2.1 (U303) did not receive a transactive talk code (another kind of talk code, beyond the scope of this paper, had been applied). Rather than share her idea verbally she chose to "speak" through the model, and instead drew out her idea. Because the collabrified nature of WeModel allowed Mary to immediately see Hannah's idea, it may have been easier for her to illustrate her point in this way. This represented a unique interaction both with her partner and with the app, and presented an opportunity to learn more about her thinking than was provided through her verbalized utterances. Despite the fact that Hannah did not explicitly externalize an idea, it may be assumed that whatever she drew was representative of her thinking, and thus may be viewed as an

externalization, or more accurately, given Mary's previous utterance (U302), an alternative idea or a higher-level transactive talk code. Without knowing for sure what Hannah proposed/drew in relation to what Mary had first suggested, it is unclear whether it would have been an addition or minor modification to Mary's idea, and thus deemed "integration consensus," or an entirely new idea in disagreement with Mary's idea, and thus "conflict consensus."

These concerns stem from limitations both in the data collected, and in the choice and application of the coding framework. Although we had student discourse throughout the unit, we only collected final form student artifacts. Making connections between these presented challenges, especially when students spent long amounts of time discussing and generating a model that was later "lost" by the technology, requiring them to reproduce their model, this time with much less talk. Though it was technologically possible, data from screen-capture technology had not been collected for this study. Using screen-capture data in future studies of this nature may help to address these methodological limitations. Specifically, the prevalence and relative ease of the use of screen capture technology on mobile devices would allow for data collection and eventual analysis of the process of artifact development, not just the final product (for examples of studies that used screen capture, see Jeong, 2013; Zahn et al., 2012; Suthers & Medina, 2011). Had screen capture data been collected, Hannah's utterance and her simultaneous drawing could have been matched and more information could have been known about the way in which she responded to Mary and contributed to the final product, using the synchronous drawing feature to communicate her idea. Furthermore, an appropriate transactive talk code could have been applied and factored into the content analysis.

**4.2. Rose and Uma: Using interaction analysis with a tracer to observe evidence of student knowledge building across multiple lesson tasks and collaborative artifacts.**

Many studies of collaborative knowledge building in CSCL environments rely on an examination of student discourse as a kind of proxy for collaborative knowledge construction, but few actually examined the individual and joint student knowledge that seemed to be produced (Jeong, Hmelo-Silver, & Yu, 2014). Thus, this study also analyzed the discourse between pairs relative to the individual student artifacts (e.g., pre-/post-assessments, student workbooks) and joint artifacts (produced within *WeInvestigate*). This analysis used the concept of a tracer (Roth & Roychoudhury, 1993), that is, "some bit of knowledge" (Newman et al., 1989, p.29), in an attempt to follow knowledge building across multiple tasks and lessons, and in both individual and collaborative written work products. Once tracers – content knowledge, including alternative conceptions - were determined inductively from the data, individually- and jointly-constructed artifacts, and the pairs' discourse were iteratively analyzed. In other words, for a bit of content knowledge found in an individually-created artifact, evidence of this knowledge was sought in student talk as well as jointly-created artifacts throughout the sampled lessons. Conversely, when a bit of knowledge was shared verbally, evidence of it was sought in individually- and jointly-constructed artifacts. Lastly, jointly-created artifacts were "dissected" for bits of knowledge and the students' discourse and individually-created artifacts were examined for evidence of the same knowledge. The following example from the case of Rose and Uma is included to illustrate the use of interaction analysis to uncover students' conceptions, and the use of a tracer to analyze students' knowledge across multiple tasks and collaborative artifacts.

Excerpt 2.2 illustrates a discussion between Rose and Uma as they began to work on their bromine evaporation model. Uma began to suggest they needed to figure out how they would draw some part of their model (U192), when Rose interrupted to suggest a contribution (U193).

In Rose's suggestion, the "bowl" she referred to was shown in the bromine evaporation video. This contribution did not end up in their final model, shown in Figure 2.4. Uma did not agree with Rose's suggestion, so proposed an alternative contribution (U194). As she spoke, she began to draw her contribution on her tablet, allowing Rose to see her thinking about how to draw the molecules ("the little") (U195). Rose did not disagree or stop Uma, so Uma continued drawing and externalized another contribution to the model (U196). Rather than taking up Uma's suggestion that Rose draw the gas stage of their model, however, Rose monitored Uma's drawing (i.e., they both had joint attention) and suggested a new contribution, that she draw a "wave" (U197). Uma did not acknowledge Rose's suggestion (U198), so Rose persisted (U199). At Uma's request for clarification (U200), Rose provided some reasoning for her suggestion (U201), but Uma did not necessarily agree (U202).

*Excerpt 2.2*

| | | |
|---|---|---|
| 3-7-U192 | Uma: All right, so now we gotta figure out how we're gonna make— | |
| 3-7-U193 | Rose: Wait first we're gonna draw the bowl. | *Externalization* |
| 3-7-U194 | Uma: No, we gotta draw the molecules. | *Conflict consensus* |
| 3-7-U195 | Rose: Oh, so can we just draw like little—oh. | *Quick consensus* |
| 3-7-U196 | Uma: First we gotta draw it as a liquid. How 'bout one of us draws the gas up here and the liquid up here. All right, so I'll draw the liquid up here. | *Externalization* |
| 3-7-U197 | Rose: Draw like the wave. | *Externalization* |
| 3-7-U198 | Uma: Oh, yeah. No circles. I can't remember that. Now they go like that and that and that. | *Externalization, No reaction* |
| 3-7-U199 | Rose: Wait, draw the wave. | *Externalization* |
| 3-7-U200 | Uma: What? | |
| 3-7-U201 | Rose: It's a wave so you know it's water. | *Externalization* |
| 3-7-U202 | Uma: I don't know. | *Quick consensus* |
| 3-7-U203 | Uma: Well, it's not water. | *Conflict consensus* |
| 3-7-U204 | Rose: A liquid. | *Integration consensus* |
| 3-7-U205 | Uma: It's Bromine. | *Conflict consensus* |
| 3-7-U206 | Rose: It's liquid. | *Integration consensus* |
| 3-7-U207 | Uma: It's supposed to be the Bromine. | *Conflict consensus* |
| 3-7-U208 | Rose: Yeah, but Bromine is liquid, Bromine is liquid. | *Integration consensus* |
| 3-7-U209 | Uma: All right, so let's draw it. And draw our…wave. | *Quick consensus* |

As we saw occur in the case of Mary and Hannah presented previously, Uma's disagreement (U202, U203) precipitated a consensus-building discussion between the girls (U202-U209) that would not have occurred (there would have been no need for it) if Uma had

simply agreed and added Rose's suggestion into the model. The result of this discussion was that

Rose's contribution, "the wave," was accepted by Uma, and can be seen in the final model,

shown in Figure 2.4. The "wave" Rose referred to represented the barrier between the liquid and

the gas above it.
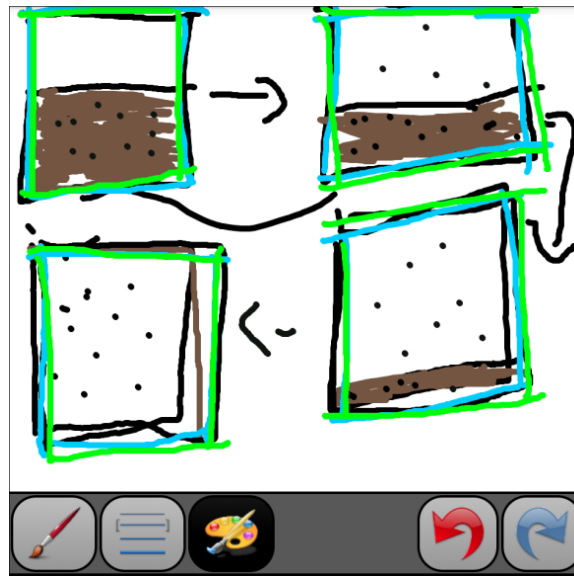


*Figure 2.4.* Rose and Uma's final bromine evaporation model.

Throughout this consensus-building discourse, Rose demonstrated a possible

misunderstanding of the video she had previously observed, as well as the fairly common

thinking among students of water as being the standard "liquid" (Kind, 2004). She referred to

what she observed in the video as "water" (U201), which, as Uma pointed out (U203) was

incorrect. By the end of their discussion they seemed to both agree that what they had observed,

and what they had to model, was a "liquid" (U208), thus necessitating drawing the "wave"

(U209).

Although the bromine evaporation video task had not been selected for further qualitative

analysis, because of how Rose described what she saw in the video, the concept of a "tracer" was

employed to examine Rose and Uma's discourse as they watched the video for evidence of

Rose's thinking. Shown in Excerpt 2.3, the discourse demonstrated that Rose had struggled to

see (U92) that the bromine, which was already in liquid form in a white bowl at the beginning of the video clip, was evaporating, as evidenced, though perhaps not clearly, as the "light brown gassy stuff" (U95), or the yellowish gas (U96). Rose then stated what she observed (U98), but was interrupted by Uma, who had begun to do the same (U99). Rose continued, now interrupting Uma (U100), and was again interrupted by Uma who simply identified the process, rather than describing what she saw (U101). In response, Rose agreed (U102). This discourse consisted primarily of elicitation, externalizing their ideas, and quick consensus. Though Rose seemed to struggle at first to see the evidence of evaporation (U92), and then later when she said she saw water getting poured in (U98), the girls did not engage in any negotiation as a result of a conflict, or disagreement of ideas, as we saw them do during the modeling task (Excerpt 2.2). Instead, they interrupted each other as they attempted to share their observations, in the end only coming to consensus on the name of the process, and not a common understanding of what they actually saw.

*Excerpt 2.3*

| 3-7-U89 | Uma: Well, what do you see happening in the video clip? *(prompt from WeRead text)* | *Elicitation* |
|---|---|---|
| 3-7-U91 | Uma: Bromine is evaporating. | *Externalization* |
| 3-7-U92 | Rose: I don't see it evaporating though. | *Quick consensus* |
| 3-7-U93 | Uma: Didn't you see that little brown stuff coming out of there? | *Elicitation* |
| 3-7-U94 | Rose: Oh, that brown stuff. | *Elicitation* |
| 3-7-U95 | Uma: Yeah, that little light brown gassy stuff. | *Quick consensus* |
| 3-7-U96 | Rose: Oh, it looks like yellowish more. Now what do we do? | *Integration consensus, Elicitation* |
| 3-7-U98 | Rose: Okay, well what do you see happening? *(prompt from WeRead text)* I see the water getting poured in, bromine. | *Elicitation, Externalization* |
| 3-7-U99 | Uma: I see bro- | |
| 3-7-U100 | Rose: Then as soon as it comes in, brown whatever starts to— | *Externalization* |
| 3-7-U101 | Uma: It's evaporating. | *Integration consensus* |
| 3-7-U102 | Rose: Yeah, evaporating. | *Quick consensus* |

By examining the discourse that occurred as Rose and Uma watched the video, Rose's misunderstanding from the modeling task can be traced back to what she thought she had observed while watching the video. During the modeling task, the girls eventually came to agreement that they were modeling a "liquid," and were able to successfully complete their model. However, evidence of Rose's misunderstanding persisted as the girls later worked to construct an explanation of their model, shown in Excerpt 2.4. Rose began to suggest a contribution for their explanation (U303). This suggestion, reminiscent of her observation about water during the modeling task, can be traced back, almost verbatim, to the video task (Excerpt 2.3, U98). This misunderstanding had not been addressed, or acted upon (e.g., by Uma, by a teacher), at the moment it arose during the video task, and the discourse that occurred during the modeling task apparently had not been enough to clear up Rose's idea about the video. Thus, her problematic idea came up again as they worked on their explanation.

| | Lesson 7: Initial evaporation model explanation |
|---|---|
| Q | Explain what happens to the bromine molecules in your model. |
| A | The bromie started a liquid. Then it started to evaporate or you say the molocules started to spread farther apartand move faster. we show this in our model by starting with liquid molecules and then it evapoateing untill it was only gas. |

*Figure 2.5.* Rose and Uma's final bromine evaporation explanation.

This time, however, Uma directly confronted Rose's misconception (U304). Rose expressed confusion (U305, U309, U311), which Uma tried to clear up (U306, U308, U310, U312). As a result of this potential knowledge building conversation, Rose revised her suggested contribution (U313). Because this contribution had been acted upon by Uma such that it was

revised by Rose, it can be considered a collaborative contribution, and was found in the final

explanation, shown in Figure 2.5. Engaging in a discussion with Uma, who understood what

happened in the bromine video, seemed to help Rose gain some understanding about what

happened in the video as well. There was no further evidence in later lessons, or on the post-test,

of her conflation of "water" and "liquid." While we know that misconceptions are extremely

persistent (Smith, DiSessa, & Roschelle, 1994), conversing with a peer to better understand the

phenomenon may have helped Rose build more scientifically accurate knowledge about the

process of evaporation. More so than when they watched the video clip, writing about their

model seemed to support Rose, with Uma's help, in making sense of the phenomenon she had

observed. In this way the jointly-constructed explanation mediated some knowledge building for

Rose.

*Excerpt 2.4*

| | | |
|---|---|---|
| 3-7-U303 | Rose: Okay. The bromine started as a liquid. Then when we poured water into it, the molecules started to— | *Externalization* |
| 3-7-U304 | Uma: No, the bromine started as a liquid. You don't pour water into it. | *Conflict consensus* |
| 3-7-U305 | Rose: What? | *Elicitation* |
| 3-7-U306 | Uma: You said the [clears throat]—sorry. You said bromine started as a liquid and that you poured water into it. | *Externalization* |
| 3-7-U307 | Rose: That's what I said. | *Quick consensus* |
| 3-7-U308 | Uma: Yeah. They didn't pour water into it. | *Conflict consensus* |
| 3-7-U309 | Rose: What? | |
| 3-7-U310 | Uma: We didn't pour water into the bromine. | |
| 3-7-U311 | Rose: They didn't? | *Elicitation* |
| 3-7-U312 | Uma: We're explaining the model [clears throat]. We're explaining the model, not [clears throat] what happened. | *Externalization* |
| 3-7-U313 | Rose: Oh, so just say bromine started as a liquid and then the molecules started to spread apart. | *Externalization* |
| 3-7-U314 | Uma: As they evaporated. | *Integration consensus* |

The interaction analysis during the modeling task in this case revealed Rose's problematic idea. This idea was traced to the video task that came before, as well as the explanation task that came after. This analysis also provided some insight into the extent to which Rose and her partner engaged in collaborative discourse during each of these tasks, and hypothesized the impact it may or may not have had on Rose's knowledge building related to a particular idea. In each task Rose's problematic idea was either not confronted at all (the video task), partly confronted (the modeling task), or directly confronted (the explanation task). It was not until Uma directly confronted Rose's entire idea that Rose seemed to revise her thinking.

The analysis illustrated by Rose and Uma's case, that is, the use of a tracer to examine potential knowledge building over time during student interactions, elucidated another limitation in our data, or rather in the overall design of the study. As we designed the *WeInvestigate* learning environment, we had not anticipated the eventual use of tracers as a means to examine potential knowledge building over time, and found it challenging to find evidence of students' thinking about specific content that could be traced throughout the unit (i.e., beyond just seeing it on the pre- and post-tests). Additionally, there was some content for which there was more evidence - because there had been greater emphasis on it in the unit - while for other content there was little. For example, there had been heavy emphasis placed on what was happening to molecules in solids, liquids, and gases at a nano-level, but less emphasis on connecting this behavior at the nano-level to observations at the maco-level. Actively building the potential for content tracers into the design of prompts meant to elicit student thinking, and doing so with coherence and consistency for the desired content, across the unit, may help researchers study student knowledge building over time in similar complex collaborative and technological contexts.

A related concern that arose in our analysis, but which might be addressed through an a priori consideration for tracers in the learning environment design, is that of sampling. In our study, a number of criteria, described previously, dictated what lessons and lesson tasks were chosen for transcription, coding, and further analysis. However, this may have limited our ability to effectively see evidence, via content tracers, of student knowledge building over time. For example, no further evidence of Rose's problematic idea, from the above case, was found in later lessons or on her post-test. We traced Rose's conflation of "water" and "liquid" back to her observation of the bromine evaporation video. However, because not all lessons and lesson tasks were sampled for transcription, and even fewer for deeper qualitative analysis, it cannot be known for sure that this idea did not arise in previous lessons that had not been sampled. Designing the learning environment in such a way that would support eventual tracing of student knowledge throughout a unit would help support researchers in more effectively identifying lessons and tasks to be sampled, depending upon what content knowledge one is interested in tracing.

**4.3. Omar and Quentin: Additional methodological challenges**

The case of Omar and Quentin is presented, in contrast with the examples provided for the previous two groups, primarily to point out additional methodological concerns. Omar and Quentin took up their teacher's suggestion to use four boxes to create their bromine model. Part of their discussion is shown in Excerpt 2.5. Omar provided several brief externalizations (U92-U96), in which he articulated an overall description of the process they were modeling (U95, U96). He then inquired about how they would represent the transition between the starting and ending states (U97). In response to Omar's elicitation, Quentin provided a suggestion, which he drew directly into their model rather than verbalize (U98), and Omar agreed (U99) with this

suggestion. Using the field notes as supplemental data in this analysis provided some hint about what Quentin's idea may have been, "Omar draws the liquid. Quentin draws a bar higher in the box, and asks Omar if they should do that. Omar says yes."

*Excerpt 2.5*

| | | |
|---|---|---|
| 2-7-U92 | Omar: Liquid. Ah. | |
| 2-7-U93 | Omar: Okay, and then the last one's gas. *(more than 10s pass before the next utterance)* | *Externalization* |
| 2-7-U94 | Omar: Gas. Liquid. | |
| 2-7-U95 | Omar: Liquid then goes to… | *Externalization* |
| 2-7-U96 | Omar: It'll be evaporation. | *Externalization* |
| 2-7-U97 | Omar: How would you do the other two? *(more than 10s pass before the next utterance)* | *Elicitation* |
| 2-7-U98 | Quentin: We can do that. | *[Externalization]* |
| 2-7-U99 | Omar: Mm-hmm. *(more than 10s pass before the next utterance)* | *Quick consensus* |
| 2-7-U100 | Quentin: I'm gonna see if I can squeeze in gas. | *Externalization* |
| 2-7-U101 | Omar: See if we could squeeze it what? | |
| 2-7-U102 | Quentin: Gas. | |
| 2-7-U103 | Omar: Gas? | |
| 2-7-U104 | Quentin: Nope. | |
| 2-7-U105 | Omar: Nope. It's too small. *(more than 10s pass before the next utterance)* | *Quick consensus* |

The transcript identified "larger" chunks of time (i.e., more than 10 seconds) that passed between certain utterances. There was also very little discussion between the boys for this task, especially when compared with the other two groups. When they did talk, they did not say much, and their talk consisted entirely of low-level transactive talk. The pattern of talk that emerged for these two boys during this Excerpt was basically that of two individuals who happened to be working on the same model. At one point Quentin decided on a contribution to the model – labeling "gas" (U100). Omar, who had likely been preoccupied with something he was drawing in another part of the model, requested Quentin repeat himself (U101, U103). The boys then became jointly, though temporarily, attentive to what Quentin was drawing.
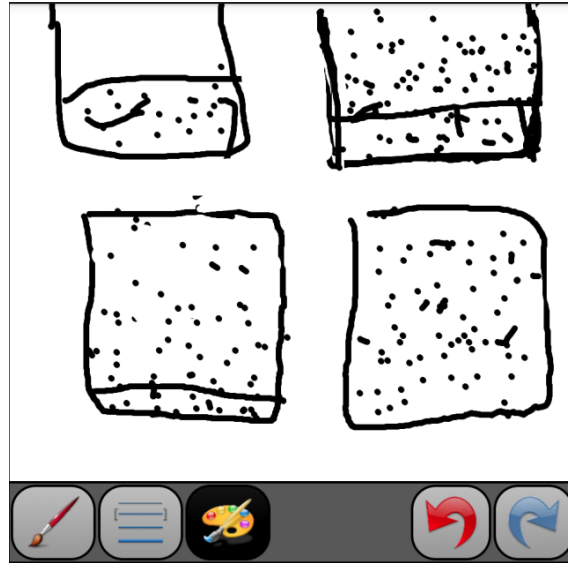
*Figure 2.6.* Quentin and Omar's final bromine evaporation model.

Because they seemed more focused on drawing than engaging with each other, Quentin

and Omar used the model to express their ideas, rather than explicitly verbalizing them. This

sharing of ideas through the model represented implicit externalizations of their ideas (e.g., U98,

U100). The collabrified nature of WeModel allowed these drawn externalizations to become

immediately available for review and response by the other person (e.g., U99, U101). Even if the

other person did not choose to respond, it could be assumed that they did at least witness the

externalization. A lack of explicit response may be considered assent to the contribution(s). In

the case of Mary and Hannah the model mediated the discourse between them as they made

reference to it and drew as they were sharing their thinking. It is possible that Omar and

Quentin's talk in these utterances was evidence of similar use of the model, that is, as a mediator

of their thinking. However, unlike what we saw with Mary and Hannah's talk, Omar and Quentin

did not often respond to their partner's drawn externalizations. The model may have been able to

mediate each student's thinking, however it did little to mediate their verbal discourse, which

remained sparse and devoid of high-level transactive talk.

Because there was little explicit discussion, even as they drew, it was not known with surety who contributed what to the model, and whether the boys modified each other's drawings without verbalization. Further, the little information about students' thinking and contributions relative to the final model (Figure 2.6) that could possibly have been gleaned from the talk in Excerpt 2.5 would have been irrelevant because later in the lesson Quentin erased the model they had produced as a result of talk in Excerpt 2.5 and constructed the final model. Excerpt 2.6 shows some talk that occurred between Omar and Quentin at the end of the day's lesson, as their teacher reviewed the evaporation model with the whole class. Upon comparing his and Omar's model to the one the teacher drew on the board, he judged their model as being an incorrect representation (U202, U206), and took steps to fix it (U203, U205). Despite Omar's disagreement that they "did it wrong," he did not move to stop Quentin from whatever changes he made to their model.

*Excerpt 2.6*

| | |
|---|---|
| 2-7-U202 | Quentin: [Whispers] We did it wrong. |
| 2-7-U203 | Omar: [Whispers] Oh, oh, oh. What are you doing? |
| 2-7-U205 | Omar: [Whispers] Why are you doing that? |
| 2-7-U206 | Quentin: [Whispers] We did it wrong. |
| 2-7-U207 | Omar: [Whispers] No, it's not wrong. [Singing] Arrow bright, arrow bright [humming]. |

Given that one of our research goals was to examine the relationship between students' thinking and the ways in which they interacted with each other to create collaborative artifacts to represent their thinking via synchronous technology, cases like Omar and Quentin's presented some additional methodological challenges. Similar to the issue raised in the discussion of Mary and Hannah's case, because our data did not include all versions of the model created by Omar and Quentin, there was no way to know what their original model looked like, or how it

compared to their final model, which did not technically even represent their thinking. A further

complication in this case was that Omar and Quentin did not verbalize their ideas very often.

One suggestion may be to sample such that only moments in which students are engaged in talk

that contained more features characteristic of desirable science talk, or talk that has been

demonstrated to have benefits for student learning (e.g., more high-level transactive talk, more

content-focused talk), would be qualitatively analyzed. However, as this kind of talk is more rare

in classrooms, this sampling would remove a lot of the natural talk that occurs between students

from the analysis, and therefore a large portion of the "picture" of a class of students using

innovative apps like *WeInvestigate* would be missing.

It has been said that writing is thinking (Emig, 1977), and similarly it may be said that

drawing is thinking as well (Larkin & Simon, 1987). As mentioned previously in the discussion

of Mary and Hannah's case, a study such as this presents an opportunity to examine a different

kind of student discourse, which may provide much more insight into student thinking than

sometimes gets verbalized, as evidenced by Omar and Quentin's case in which very little was

actually verbalized. Field notes focused on capturing different stages of students' drawing

process, and which document moments when students draw based on their own thinking versus

when they modify their partner's drawing/thinking, may be helpful. However, screen capture

technology, as mentioned previously, analyzed in conjunction with student talk and field notes,

should provide more access into the thinking, and collaborative, processes.

Another challenge that arose for this particular pair of students was the fact that in Lesson

7, their model was not necessarily representative of their thinking and their discourse throughout

the lesson. There was no way the content analysis could have predicted the mismatch between

their talk and the final model. Only the qualitative analysis of the boys' talk revealed this

distinction. This speaks to the usefulness of utilizing multiple methods when engaging in studies like this. One may argue that the boys could have appropriated this knowledge from the whole class discussion, in which the teacher shared the model, as a "revision" of their initial model. However, there was no evidence in the data we collected that any additional collaborative talk or thought contributed their final model. Here again screen capture technology may be utilized by researchers to see the process, including to what extent their original model differed from their final model, and which student contributed the most to each of these versions.

## 4.4. Ensuring reliability and validity

In this study, quantitative and qualitative methods were used in combination to ensure reliability and validity. Of primary concern were "experimenter effects," that is when the researcher acts in such a way, perhaps unwittingly, as to produce expected and desired results (Rosenthal, 1966). Experimenter effects can occur during analysis and interpretation. In an attempt to minimize experimenter effects during coding, consistent with quantitative methods, 20% of the transcripts (randomly selected) were coded by a second coder from the *WeInvestigate* research team, who had also been present in the classroom during data collection. Only on-task utterances were double-coded. Following this, inter-rater reliability calculations were performed. Although it is almost impossible to completely eliminate researcher bias because the researcher cannot remove the lens through which s/he looks at all aspects of the study, the researcher can be forthcoming in identifying their lens and acknowledge that it may influence how the results are interpreted (Maxwell, 2005). Consistent with qualitative methods, this was done through discussions with, and reviews of writing by, another researcher, who had also been present in the classroom throughout the study.

Another way to address issues of researcher bias, and reliability and validity of findings is through triangulation (Stake, 1995). In the context of this study, we utilized an expanded definition of triangulation, which included not just multiple measures, but also multiple data sources and multiple methods, as described throughout this paper (Lather, 1986). The combination of multiple methods helped ensure reliability and validity of findings in that what was found as a result of quantitative analysis was supported (or not) by what was found through qualitative analysis and vice-versa. Additionally, the use of multiple data sources helped confirm or refute findings. As qualitative analysis proceeded it was sometimes desirable to refer back to the content analysis for this purpose. For example, Figure 2.7 shows another slice of the data, which included a comparison of each student within and across each group during the modeling task in Lesson 7. This Figure showed that Rose and Uma engaged in more high-level transactive talk than did the other two groups. Even in the brief excerpts presented in this paper for illustration of the qualitative analysis we see this to have been the case as well. Thus, in this instance, findings from multiple methods converged in the case of Rose and Uma.

In another example, the use of multiple data sources helped resolve discrepancies between data. For example, Figure 2.7 also revealed that Omar talked about a third more than did Quentin, from which it may be hypothesized that Omar may have contributed more ideas to the production of the artifact than Quentin. However, analysis of the log files provided evidence that their contributions may have been much more balanced: Omar drew 296 times and Quentin drew 290 times. Qualitative analysis revealed, as partly described in the example above, that the boys' discourse may have also occurred via their model, which would support the greater balance in participation demonstrated by the log files.

**On-task talk codes per student for evaporation model task in Lesson 7**

Legend:
- No Reaction
- Conflict Consensus
- Integration Consensus
- Quick Consensus
- Elicitation
- Externalization

Groups: Group 1 (Hannah, Mary), Group 2 (Rose, Uma), Group 3 (Omar, Quentin)
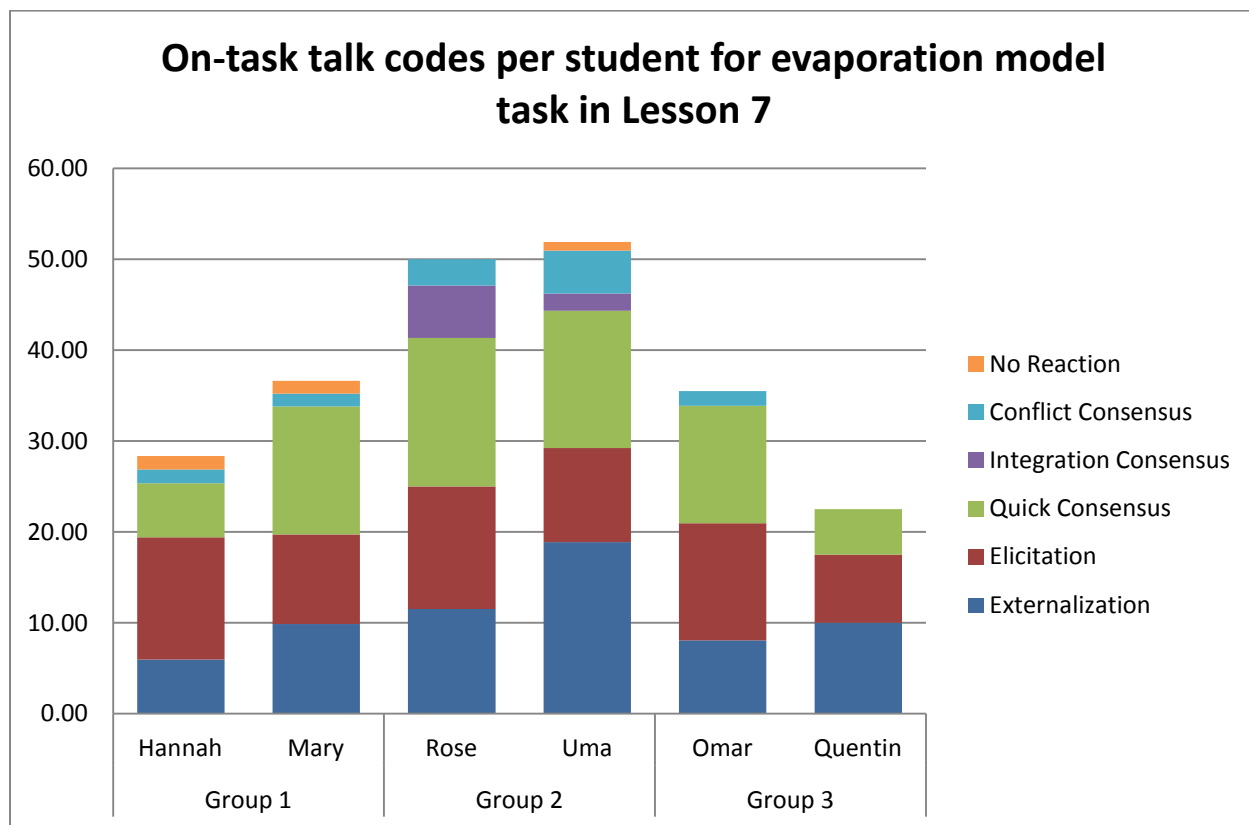
*Figure 2.7.* Total percent of the on-task transactive talk codes per student for the bromine evaporation model task.

## 5. Conclusion and Implications

This paper presented a discussion on the use of multiple analytical methods, in alignment with multiple sources of data, and the larger research purpose, as a means of analyzing "messy" and complex classroom data, that is, interactions between pairs of sixth grade students, their interactions with a tablet-based app, and the artifacts they jointly produced, in order to characterize the collaborative nature of these interactions and the potential knowledge building that may have occurred as a result.

The use of multiple data sources and multiple methods was necessary for the study of pairs of students' collaborative knowledge building discourse within a mobile digital learning environment. The nature of the curriculum necessitated students' collaborative engagement in the scientific learning tasks, and the nature of the technology, with its synchronous collaboration

embedded within the different features of the app, supported this endeavor. In order to understand what was taking place, and how it was taking place, within such a unique learning environment and traditional school context, multiple sources of data and methods were used to triangulate findings. The resulting volume of data, and the complexity of that data, too, demanded multiple analytical techniques, each of which informed and spoke to the others.

Quantitative content analysis included coding each on-task utterance, tabulating frequencies, and representing them visually to seek patterns in the data. In this paper, the findings for the transactive talk codes were presented at the unit level, the lesson level, the task level, and the student level, with the task level representation perhaps providing the most insight into patterns of talk across groups for different types of tasks. These different views of the data, along with other sampling criteria, assisted decision-making about further sampling of lessons and tasks for qualitative analysis. While these quantitative views provided information about the "what" and "when" of the transactive talk patterns within and across groups, the qualitative interaction analysis of sampled lessons and tasks provided information about the "how" of the collaborative knowledge building discourse between students and artifacts as they engaged in the *WeInvestigate* learning environment.

As data analysis progressed some methodological concerns and implications for future studies of this nature arose. Because we sought to investigate collaborative knowledge building as a process, we found it somewhat problematic that we only had access to students' final form artifacts. Because the artifacts were produced jointly with a partner, trying to resolve students' talk with what was produced was not always easy when we could not always confidently identify each student's individual contributions, and when some of their discourse occurred through the artifact itself. This became even more challenging when the students did not verbalize the ideas

that were put into (or were eventually left out of) the final artifact. In addition, artifacts were sometimes accidentally lost, or students chose to completely redo them, often verbalizing less each subsequent time they revised an artifact, providing little insight into the changes they were making or why. The collection of screen capture data may address these concerns. It would capture the process of what students were producing. Analyzed in conjunction with their discourse, it could provide greater insight into how they were producing the artifact (e.g., who was contributing what), and the knowledge that was being shared.

However, collection of screen-capture data would also present new challenges for analysis. Screen capture data would be similar to video data, but would require audio accompaniment in order to provide some context as to what was occurring on the screen. New ways of coding screen capture in conjunction with accompanying talk may also be necessary, depending upon one's research questions. Analysis of transcripts of talk at the utterance level is time-intensive as it is (Howe, 2010); adding simultaneous analysis of screen capture data would further extend the length of time required to do this kind of work.

The volume and complexity of data and analysis may be unavoidable for studies in which one wants to deeply understand processes such as learning and collaborative interaction. However, very mindful sampling of the data in order to reduce some of the volume, without losing the ability to study specific phenomena over time, may help. A related implication that also arose during analysis was the idea of building into the design of the learning environment in which a study occurs - as well as into the study design - the anticipatory use of tracers to examine students' learning and interactions around specific content over time, and to sample lessons and tasks for study accordingly.

In conclusion, although the examples presented here provided brief "snapshots" into the use of multiple analytical techniques, they demonstrated how quantitative and qualitative methods could be used iteratively across multiple data sources and at different levels, to provide both an overview of different cases, as well as a more detailed view within and across cases, of the nature of the collaborative knowledge building discourse that occurred for pairs of sixth grade students within a face-to-face and synchronous mobile digital learning environment.

| CODE | DESCRIPTION/RULES | EXAMPLES FROM THE DATA |
|---|---|---|
| *Dimension of social modes of co-construction codes* | | |
| Externalization | Applied to student utterances that were considered new contributions to the discourse with respect to content-related talk. Externalization was only applied the first time a student said something; a unique utterance. The exception to this rule was when the student was speaking to a new person, e.g., when a teacher came over to check in, or if the student repeated what they had already said, but then added more onto it. This is because externalizing their knowledge to a new person gives that person a chance to respond to that knowledge, thus opening up the possibility for more, new knowledge to be shared. Apply code for a contribution to the original idea (when it does not fit as another form of transactive talk). This most often happens when a student builds on his/her own initial idea, even if the utterance is several utterances later. (Noroozi et al., 2012). Because Elicitation leads to others externalizing their ideas, the utterance following a partner's (or teacher's or text's) elicitation is coded as externalization if it is a response to that elicitation. | Rose: Can I write it? [elicitation] Uma: Okay. We should make the water brown. I don't know why. I just feel that. [externalization] |
| | | Uma: Yeah. What did you observe happen in the simulation? [question from text] Rose : It went really slow, it went really fast, and it went medium. [externalization] |
| Elicitation | Apply this code when students question their partner to receive additional information. Typically, elicitation is a question, but can also comprise requests for feedback that demand an affirmative or a negative response from a partner. Elicitation is coded for all questions asked. If the partner does not respond to the elicitation it receives the No Reaction code. | |
| Quick consensus building | Apply this code when students simply agree or disagree with the ideas their partner contributed, without further elaboration or critiquing. An utterance with this code will usually follow an externalization utterance. This code does not apply when a student is just answering yes/no to a question. The exception to this rule would be when the student is eliciting a response from another student that really is more of a statement, and are looking for agreement because they finish with "Right?" (i.e., look for instances of agreement/disagreement, vs. when a student is asking/answering yes or no). | Mary: Yep. Draw the line. No. No, no, no. It's liquid. You have to draw the line cuz it's a liquid. It sits in a puddle. [externalization] Hannah: Oh, okay. I didn't know it was in that. [quick consensus] |
| Integration-oriented consensus building | Apply this code when students build on the ideas of a partner, integrate multiple ideas or viewpoints, or take over the perspective of a partner. An utterance with this code will usually follow an externalization utterance. Integration consensus can also be applied when one student is typing and speaking aloud while doing so, and the other student is adding to their words. The exception to this rule is when a student is simply reading over what has been typed without | Hannah: Okay. The motion. The motion. The high temperature affected cuz if you pour hot water into something it goes [sound effects] like fireworks off. [externalization] Mary: When you heat up water it boils and then it turns into |

| | | |
|---|---|---|
| | adding anything to it. | water vapor. [integration consensus] |
| Conflict-oriented consensus building | Apply this code when students do not accept the contributions of their learning partners as they are. They operate on their partner's reasoning by critiquing and modifying their contributions or presenting them with alternatives. An utterance with this code will usually follow an externalization utterance. | Mary: Then, number four is a liquid gas. [externalization] Hannah: No. It's a gas or a liquid cuz condensation is that, or you could continue. Some steam comes up, and it goes to the window and saw water. [conflict consensus] |
| No Reaction | When learners did not respond to elicitations and externalizations from their learning partners, we coded the chronologically next message as "no reaction" (Noroozi et al., 2012). Even if the utterance immediately following an elicitation or externalization is coded Off-Task, still code that No Reaction. | Marcel: What evidence from your experiment do you have to support this? [elicitation] Quentin: Just looking at the pictures. [no reaction] |
| Affirmative/ Negative response | Apply this code when a student simply answers yes, no, I think so, I guess, etc. to the other student's elicitation. | Hannah: Okay, wait, wait, wait. Does the model show the actual smell? Mary: Yes. [affirm/neg response] |

| *Epistemic dimension codes* | | |
|---|---|---|
| Coordinative talk | Apply code when utterance relates to coordination, planning, and monitoring of the learning task. This talk includes when students delegate who draws/write what and where in their model or explanation. It also includes talk about the task at a meta-level. e.g., when a student describes out loud what they are writing/drawing. | Uma: First we gotta draw it as a liquid. How 'bout one of us draws the gas up here and the liquid up here. All right, so I'll draw the liquid up here. |
| Content-related talk | Apply code when utterance is about science content that is being covered in the lesson, was covered in previous lessons, or other science knowledge brought into the conversation by a student that may/may not be specific to the lesson. This includes questions about content, not just statements (usually questions from the text). Also apply code when there is talk about predictions or evidence (science practices). | Mary: We just have to make 'em more spread out like as we keep going. [content and model] |
| | | Rose: I have lines that says that they're moving. [content and model] |
| | Utterances may also contain one of the following sub-codes of Content Talk: <br> • Mechanics - Apply code to utterance when students are talking about pronunciation or spelling of science terms; when students are talking about capitalization or punctuation when writing text; when one student provides the other student with the correct pronunciation of a word <br> • Model - Apply code to utterance when students are talking about what should go into the model in terms of features, or how the model looks; when students are writing explanations and refer to their model; when students are trying to figure out the representations in a | Rose: You got a typo.[mechanics] |
| | | Uma: How do you spell flew [chuckles]? [mechanics] |
| | | Quentin: I'm making it 3D. [model] |
| | | Quentin: Yeah. It looked like really, really hard to get all the blue ones. One, it looked hard to get one all the way to the gas sensor, cuz they kept bumping and stuff. [model] |

| | | |
|---|---|---|
| | simulation; when students are observing what they see happening in a simulation; when students are talking about manipulating the model (simulations).<br>• Phenomenon Observations - Apply code to utterance when students are making observations or asking questions about different phenomena, usually videos; when students are talking about the real-world phenomenon (e.g., smell) as they observe the simulation; when students are making connections between the phenomenon and the model or writing they are doing at the time. | Marcel: It's down at the bottom. Are we supposed to remove the barrier? [model] |
| | | Mary: Mirror—whoa. Mirrors are that shiny. That's really shiny. I should have a piece of that so that I can have the mirror all the time. [phenomenon observations] |
| | | Uma: All right, I'm gonna make the water brown because bromine is brown. [phenomenon observations] |
| Technical talk | Apply code when utterance is about the technical features of the learning environment. For instance, apply this code when students talk about closing and opening one of the app features (WeWrite, WeModel, etc.); when they talk about where they need to go in the tablet, or on which side of the screen they open an activity; when students are using the talk to text feature on the tablet, etc. | Uma: Join session. |
| | | Mary: Let's go to "we write." |
| | | Rose: Activity five. On this side? Stop. |
| | | Rose: (into tablet) It starts as a liquid, period. |
| *Additional codes* | | |
| Curriculum | Apply this code when students are reading or taking direction from the curriculum (tablet). They may also reference "it" providing some guidance or instruction.<br><br>Resource Use - is a specific type of Curriculum use when students refer to some aspect of the tablet workspace (including workbook) as in the Technical talk code, and beyond how it's use is described in the curriculum, for instance, when they are using the pop-up definition tool. | |
| Interlocutor | Apply this code when a student talks with any person other than their partner (e.g., a teacher, another student, a researcher) | |
| Repeat | This code is meant to help avoid artificially inflating or over-coding. It is applied when an utterance is a repeat of something the student has already said. It may be applied to an utterance by itself as in the case where student 1 says something, and student 2 says "What?" and student 1 repeats him/herself. In this case, apply relevant talk codes to the first S1 statement (or most complete S1 statement), and then S2's eventual response. The "what?" and the repeated response receive the Repeat code. When having to enter text in WeWrite, students often lose text accidentally, or use the speech to text function. In doing so, they must repeat a lot of what they have already said. When a student has repeated verbatim, or almost verbatim, what they have already said while working in WeWrite, apply the Repeat code. | |
| Inaudible/ | Apply this code when something a student says is cut off, or | |

| | |
|---|---|
| Incomplete | partly inaudible or incomplete. If you can get some sense of what the student was saying, then also apply other relevant codes. If there is nothing of any substance, just code incomplete/inaudible by itself. |

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# CHAPTER III

***WeInvestigate*: The design of a tablet-based science app to support "collabrified"**

**knowledge building**

## 1. Introduction

As they have for many years now, digital technologies will continue to influence the lives of most individuals. Today, teachers in K-12 schools are educating students who will spend their entire lives in a technologically-rich society. Additionally, recent education trends such as "blended learning" (e.g., Horn & Staker, 2011), "one to one instruction" (e.g., Penuel, 2006; Chan et al., 2006) and "flipped classes" (e.g., Horn, 2013) reflect the public demand for technology in schools, and have led to increased popularity in the use of mobile devices in K-12 educational settings (Banister, 2010). Thus, the importance of technology in our society has influenced a desire - perhaps even a necessity - for technology use in schools.

The ability to effectively collaborate to accomplish tasks and solve problems is also very important in our global society. The intellectual demands and complexities of modern adult life - perhaps instigated by technological advances and our growing attachment to and reliance on technology - are many, varied, and subject to rapid change (Kuhn, 2015). Many of the demands of adult life are encountered in collaborative contexts. In order to be "21st century ready," therefore, young people must gain competence in, and be comfortable with, working collaboratively to address problems and meet objectives that are unique to life today. Hence, the importance of collaboration in our society is also reflected in what we expect for our students in

schools.  Given the emphasis in our society on collaboration and technology use, "technology-rich collaboration" has been identified as an essential 21st-century skill for students to master (NRC, 2010; P21 December 2009).

Further, collaboration and technology use are fundamental to the work of many professionals; specifically, for the purposes of this paper, to the work of scientists. Collaboration is necessary to advance scientific knowledge (NRC, 2012). Though new ideas may be developed individually or as a group, the theories, models, and methods – the things that constitute the norms and knowledge of science – are developed collaboratively by scientists working together over extended periods of time.  New technologies have not only advanced the capabilities of scientists in data collection and representation, modeling, etc., new technologies have also extended the collaborative practices of scientists, allowing for instant, synchronous, global communication, not only with other scientists, but in cross-disciplinary endeavors, as well as in communication with lay audiences (NRC, 2012).  Because it is expected that students will be learning science through practice, authentic science in school will require students engaging collaboratively, and using technology in similar ways, as articulated through ambitious reform efforts (NGSS Lead States, 2013; NRC, 2012).

Educational technology and science education researchers have been calling for and designing content-based, pedagogically forward-thinking technology integration for decades (e.g., Fisher, Dwyer, & Yokum, 1996; Roblyer, Edwards, & Havriluk, 1997; Linn et al., 2004; Reiser et al., 2001). This is - in part - because advanced learning technologies, coupled with inquiry-based science curricula, may offer students new ways to access and participate in three-dimensional science learning (NRC, 2012; Williams & Gomez, 2002). Moreover, reform documents (NGSS Lead States, 2013; NRC, 2012; CCSSO/NGA, 2010) call for technology

integration in ways that are not only authentic to how science is done, but also to support student use of tools for 21st century collaboration and communication.

The work presented in this manuscript responds to calls for the integration of collaboration and technology, particularly mobile technologies (PCAST, 2010), in schools, and to address current ambitious reform efforts (NGSS Lead States, 2013; NRC, 2012), through the design of an app-based K-12 collaborative science learning environment. As mobile technologies grow ever abundant in our society, more education contexts are investing in mobile technology to support teaching and learning (e.g., Roscorla, 2010). Therefore, the need for development of effective learning environments within these technological contexts increases. Although a wide variety of apps for use on mobile devices, such as tablets, have been developed specifically for educational purposes, and many curriculum developers see tablets as the next frontier for their products, there have not yet been many K-12 research studies on the functionality and effectiveness of apps or tablets for student learning (see e.g., Enriquez, 2010; Chen et al., 2010 for college-level studies). In a review of apps designed to run on iPad and other iOS devices, Murray and Olcese (2011) found that most of the apps involved students' consumption of content, rather than the creation of - or collaboration around - that content. At the time of their study, not a single app, in their evaluation, considered current understandings about how people learn (Murray and Olcese, 2011). Thus, there is also increased need for empirical research on the design and educational effectiveness of app-based learning environments, especially for our purposes as science educators, on apps for use with tablet devices that are meant to engage students in the kind of ambitious depiction of science instruction that is captured in current reform documents such as the *K-12 Frameworks for Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

To that end, we designed a mobile app-based science learning environment and studied its collaborative use in a sixth grade classroom. We were interested in the feasibility of embedding an entire well-researched, innovative curricular unit into a single app for use with mobile devices; to investigate the synchronous collaborative capabilities of students using the app to engage in scientific practices; and to study student learning outcomes within a context where the teacher and students had not previously engaged in teaching and learning science in this way.

The purpose of this manuscript is to elucidate the design rationale, and development, of a tablet-based synchronous science app called *WeInvestigate*, designed to support student science learning through collaborative engagement in science practices. Specifically, we describe our theory, or vision, of collaboration, and the design principles and features that were incorporated into *WeInvestigate* based on this theory, to support collaborative scientific modeling and model-based explanations. Following this, Chapter 4 reports the findings of a pilot classroom study of the use of *WeInvestigate* by sixth grade students. In Chapter 4 we hypothesize the impact that the design principles described here had on students' collaborative engagement in science practices. We also suggest implications for future design and research of *WeInvestigate*, and similar educational technologies.

## 2.  A vision of collaboration in science classrooms

### 2.1.  Practical and theoretical arguments

In designing the *WeInvestigate* learning environment, it was necessary to articulate our vision of collaboration, to identify the challenges of incorporating student collaboration in classrooms, and to establish the characteristics of collaboration that are at the core of the social practice, and that we wanted students to experience, that would help to address the challenges

identified, and that would be effective in engaging students in thinking and reasoning together about scientific phenomena.

Kuhn (2015) identified two commonly used arguments for the integration of student collaboration in schools. One argument, articulated above, is that of collaboration as a necessary "21st century skill" (Dede, 2010; NRC, 2010; P21 December 2009), and that students should be collaborating for the sake of gaining a life skill that will be useful and necessary in their adult lives. Another more long-standing and popular argument suggests the use of student collaboration as the means to some intellectual end (Doise, 1990). For example, there has been a great deal of research in education that has shown that learning from others supports student learning (e.g., Brown and Campione, 1994; Hoadley & Linn, 2000; Scardamalia & Bereiter, 1996). Social interaction and collaboration allows students to hear, consider, and build upon others' conceptualizations (e.g., Miyake, 1986; Hogan et al., 1999). Also, internal thought processes are made visible during externalization in social interaction and this process fosters cognitive achievements, as it forces the student to construct a better mental model about the topic (e.g., Palincsar & Brown, 1994). Each student brings his or her own partial, and different ideas to a shared problem-solving process, and, as a result of social interaction around that problem, all students involved appear to improve their understanding (Lehtinen, 2003).

Meeting the ambitious reform efforts mentioned previously requires supporting student collaboration through engagement in science practices. Thus, a third argument for student collaboration, that may be considered a disciplinary melding of the two arguments identified by Kuhn (2015), is that students should engage collaboratively because it is authentic to the work of scientists, and to engage in this practice of science helps to enculturate students into more deeply learning science content (Brown, 1995). Developing a deep understanding of science as a social

enterprise, as current reforms suggest, entails engaging students socially in the practices of science. The collaboration that occurs between students who are engaged in authentic scientific practices, results in student discourse that is distinct from everyday conversations and routine school-based discussions (Cobb & Yackel, 1996). It represents a unique form of socially situated reasoning and knowledge building (Cobb & Yackel, 1996). For example, the process of developing and using models is an inherently social experience, and supports a language-rich learning environment within which students engage in scientific discursive practices (Bottcher & Meisert, 2011; Passmore & Svoboda, 2012). In this environment, student thinking is made visible, and students have opportunities to engage in thoughtful discussions about the specific science concepts being studied, as well as about the model and practice of modeling itself (Wu & Krajcik, 2006; Lehrer & Schauble, 2010). Engaging in collaborative discourse based in science practice may enable students to develop deeper disciplinary conceptual understandings (e.g, Brown, 1995; Von Aufschnaiter et al., 2007; Zohar & Nemet, 2002).

Our approach to the design of a collaborative and technology-based science learning environment is grounded in this last argument, viewed as an integration of the first two. This argument, and therefore the design work described in this paper, is further grounded in an overall social constructivist approach to learning. The social-constructivist paradigm maintains that knowledge is socially constructed, and that learners should be involved in a process of collaborative knowledge construction to achieve conceptual change (Vygotsky, 1978). In this sense, learning is knowledge construction. All knowledge begins socially and is external, manifest in conversation, and then becomes internalized, developed in the individual learner's mind (Scardamalia & Bereiter, 2006, Vygotsky, 1978). An individual's mental functioning can be seen as being derived from and situated within that individual's social interactions with others.

Viewed somewhat differently, learning is also a process of enculturation (Brown, Collins, & Duguid, 1989), or of becoming a member of a community of practice (Lave, 1991). Learning science, for instance, entails learning to become part of the community of science, which means doing science in authentic ways. Authentic activities are considered "the ordinary practices of a community," or the work that practitioners, or experts, of that community do (Brown et al., 1989, p.34). For this study, too, "authentic" science classroom activities are those in which students are engaged in practices that mirror the work of scientists, and do so in relevant, meaningful contexts. School science communities should correspond to scientific communities (Brown et al., 1989). The school science community of practice is the one that develops in the science classroom as students (and teacher) engage in constructing knowledge and developing shared understandings.

From this situated cognition perspective, conceptual knowledge cannot be abstracted from the situations or contexts in which it is used and learned. Learning occurs naturally through activities, contexts, and community interactions (Lave, 1991). As such, learning takes place externally, and not in the minds of individuals viewed as separate from the context in which the learning occurs. The individual mind is situated within and interacts with the external world, and all learning is externally motivated. Figure 1.1, described in Chapter 1, graphically represents the situated context in which the teaching and learning in our study occurred. Students collaborated with one another face-to-face and through the app as they engaged with text, graphics, and modeling, while being immersed in the chemistry content of the curriculum. The content and collaborative activities are situated within the technology, which in turn is situated within the classroom context.

More specifically, this design work is situated within the principles illustrated by Scardamalia and Bereiter's Knowledge Building approach, which positions itself within the social constructivist paradigm, and resembles many principles of situated cognition. Knowledge building, which arose in conjunction with a technological intervention (CSILE/Knowledge Forum) (e.g., Scardamalia & Bereiter, 1994), is a special form of collaborative activity (Lipponen, 2002), that extends the ideas of engaging students in authentic activities and becoming members of a community of practice in school.  The basis of knowledge building is that authentic, creative knowledge work can take place in school classrooms. In other words, although students are learning already existing knowledge (when compared to what scientists already know), they can engage in the work that not only mirrors the knowledge and practices of disciplinary experts (i.e., scientists), but also advances the state of knowledge of the classroom community (when compared to the knowledge that students enter a science classroom with). The focus is on advancing the state of knowledge of the community by distributing knowledge and expertise across students (Scardamalia & Bereiter, 2006). Knowledge is distributed such that no one individual knows it all, and students come to school knowing different things, making for more interesting and productive exchanges between them.  Therefore, collaboration is necessary for knowledge building (Brown, 1994). Following these theoretical arguments, in order to support student science learning through collaboration, we built into the design of the *WeInvestigate* learning environment opportunities for students to work with their peers to co-construct knowledge, by engaging in authentic science activities in a meaningful context.

## 2.2.  Collaboration as a design principle

Stemming from the above practical and theoretical arguments for collaboration, and consistent with the science learning environment design literature (e.g., Singer et al., 2000), we

viewed collaboration as a design principle in and of itself, and designed instructional components and supports based on this principle. Further, given that our design approach was grounded in an argument of engaging students in collaboration as reflective of the work of scientists, and to immerse students in science learning through collaborative participation in science practice, we did not necessarily differentiate in our design between the principles for supporting student collaboration in general, and principles for supporting student collaboration in science. Consistent with our theoretical framing, and knowledge building as a process of enculturation, the instructional components and supports built into *WeInvestigate* were designed to specifically support students engaging collaboratively around the creation of "epistemic artifacts," defined as tools that serve to advance knowledge (StereIny, 2005). We wanted students to have opportunities to identify and communicate their science thinking by making predictions, drawing initial models and explanations for phenomena, presenting their individual ideas to their peers and engaging in consensus-building, or negotiation, around similar and conflicting ideas, co-constructing models and explanations, all for the purpose of wrestling with and reasoning about science concepts and phenomena. Thus, the collaboration design principles described in this paper are considered to be situated within the context of the science practices around which students were collaborating.

## 2.3. Characteristics of effective collaboration

We defined collaboration in this study as a process of knowledge building, or shared meaning construction (Scardamalia & Bereiter, 1994; Brown & Campione, 1994), or more specifically as, "coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p. 70). The medium through which students collaborate is language, both written and oral. From a

knowledge building perspective, discourse goes beyond students simply sharing their ideas and subjecting them to evaluation or feedback. Rather, in classroom knowledge building discourse, ideas are shared and built upon by other students. Per this definition of collaboration, we identified in the literature characteristics of productive collaboration.  The research community is consistent regarding the characteristics of more productive collaboration, and the desire to have students engaged in this kind of collaboration were considered in our design. For instance, we attempted to design instructional components and supports for higher-levels of transactive talk (i.e., uptake of ideas, consensus-building talk, negotiation) (Suthers, 2006; Dabbagh, 2005). Transactivity has been defined as the extent to which learners take up and negotiate the reasoning of their peers (Teasley, 1997).  Utterances in which students integrate their partners' ideas in their own reasoning, or critically discuss their partners' contribution, are considered highly transactive and are associated with positive learning outcomes (Teasley, 1997). There are indications that the more transactive the student discourse, the more students individually benefit from collaboration with peers (Teasley, 1997). We also built into *WeInvestigate* supports for other indicators of productive collaboration, such as the acknowledgement of ideas from a partner (Barron, 2003); joint attention, and joint artifact construction, by both students in a pair (Dabbagh, 2005; Barron, 2003) to a shared representation (Suthers, 2005; Schwartz, 1995); and ways in which the artifact being created mediated student discourse (Suthers, 2005) and vice-versa.

## 2.4.  Challenges of, or barriers to, effective collaboration in classrooms

Collaboration is very challenging to support in classrooms (e.g., Singer et al., 2000). While the potential benefits of collaboration reinforce the argument for having students collaborate to learn science, the challenges or barriers to students engaging in behaviors

characterizing productive collaboration in science, described above, were also considered in the design of *WeInvestigate*. Some of the challenges confronting both teachers and learning environment designers relate to the culture of school, or the classroom. Productive collaboration, described above, requires students to share their ideas, listen to and respond to others' ideas, and coordinate and come to consensus around the creation of artifacts. Such characteristics are not typical of classrooms (e.g., Blumenfeld et al., 1996). In our study classroom in particular, students were used to working individually, being rewarded for completing tasks (i.e., getting right answers), and competing with each other for public recognition and grades.

Other challenges relate to the students themselves, and the evenness of their participation in collaborative group work. For example, in a small group setting, there are more dominant students, who take on much of the cognitive and work load, and there are more passive students, who are willing to defer to the more dominant students, and "social loafers," who do not do their fair share, and thus do not contribute much to final group products (Blumenfeld et al., 1996). There are also concerns that students do not know how to appropriately interact with their peers to elicit and resolve conflicts in ideas, or know how to ask for help from, and give help to, peers with respect to complex science content (Blumenfeld et al., 1996). The nature of the task students are asked to do also presents potential challenges for collaboration. For instance, tasks in which students are asked to solve problems, or that have more than one right answer, are likely to encourage students to engage in some of the behaviors characterizing more productive collaboration, than tasks that require low-level recall and one solution, which are generally the norm in traditional classrooms (Blumenfeld et al., 1996).

### 3. The *WeInvestigate* "collabrified" learning environment

In response to calls for the integration of collaboration and technology, particularly mobile technologies (PCAST, 2010), in schools, and to address current ambitious science reform efforts (NGSS Lead States, 2013; NRC, 2012) that advocate for learning science through the engagement in science practices to explain phenomena and solve problems, we designed an app-based K-12 collaborative science learning environment, called *WeInvestigate*. New, mobile technologies, like *WeInvestigate*, have the potential to support student collaboration around science practices. Despite the criticism, or worry, that technology integration in classrooms will reduce face time, and limit social interactions, technology actually has the possibility to facilitate social interaction between teacher and students, and among students (e.g., Lehtinen et al., 1999; Campbell et al., 2010).  With the recent tablet boom, technology has become much more portable, and provides some ease of access, which enables learning with the device in the same space and at the same time as the classroom learning environment, in a more natural, less intrusive way (Roschelle, 2003).  Studies have found that combining the use of computer technology and collaborative learning has benefits for student learning (e.g., Janssen & Bodemer, 2013; Lou et al., 2001; Manlove et al., 2009). Embedded in the design of the *WeInvestigate* app, therefore, is the stance that technology provides the facilitative infrastructure to support effective collaborative knowledge building discourse, both situated in the technology, as well as through face-to-face communication.

There is already considerable precedence for the use of technology and mobile devices in K-12 classrooms to support scientific inquiry and student collaboration (Roschelle et al., 2005; Barab & Luehmann, 2003; Kim & Hannafin, 2004; Barab et al., 2000; Jackson, Krajcik, & Soloway, 2000; Mistler-Jackson & Songer, 2000; Sadler, Whitney, Shore, & Deutsch, 1999). Much of the value from integrating technology in science classrooms can be found in its ability

to allow students to work with enhanced visualizations of complex concepts and processes. Powerful models, visualizations, and dynamic multimodal capabilities of computer displays can create novel learning environments (e.g., Linn et al., 2003), and provide a powerful means of bridging between concrete experience and abstraction, for which scientists themselves use technology (Gordin and Pea, 1995). We built on this plentiful technological presence in the science education literature in our design of the *WeInvestigate* collaborative science learning environment.

When talking about the *WeInvestigate* learning environment it is important to note that we actually refer to three main components: (1) the technology, which consists of an app designed for mobile devices, and which contains four distinct "modules" (WeRead, WeModel, WeWrite, WeWatch), (2) the written curriculum (i.e., the readings and activities that are contained within the *WeInvestigate* app), which were synergistically designed for integration with the mobile app, and (3) the teacher's guide to support the teacher's enactment of the curriculum within the mobile device.  Together, these three facets comprise the *WeInvestigate* digital learning environment, or more simply "*WeInvestigate*." Although each of these three facets are integrated with one another in practice, for the purpose of articulating our design process and rationale, the following sections will describe each facet in turn.

In the rest of this paper we provide the reader with an overview of the learning environment. We begin with our choices of content and practice to support three-dimensional learning in science. Then we discuss the choice to adapt a published curricular unit, and texts. We describe the specific features and spaces in the technology, followed by an overview of the combined synergistic design of the technology and curricular unit to describe the app itself. Throughout these sections we articulate the specific details of the collaboration design principles

that were built into *WeInvestigate*, and provide illustrative examples from the learning environment. We conclude this paper with a summary of the collaborative supports incorporated into *WeInvestigate*, and reflect on some of the challenges we encountered.

Chapter 4 will further illustrate these design principles with respect to their effectiveness as evidenced by outcomes during a classroom pilot study of *WeInvestigate*. Although there were other design principles that went into the design of *WeInvestigate*, the focus of this paper is on elucidating the collaboration design principles. We also remind the reader that the collaboration design principles all reflect our desire to have students engage collaboratively around modeling tasks. In our view, the modeling task does not solely consist of the model construction itself, but also pertains to the students' observations and discussions of the phenomenon about which they will construct their model, and the discussion and construction of their model-based explanation following model construction (and which occasionally even led students to revise some aspect of their model). We see each of these tasks as integral to the modeling process. Thus, we include in our discussion below the ways in which we attempted to support student collaboration around all of these modeling tasks.

## 3.1. The Written Curriculum

As will be described later in more detail, *WeInvestigate* is a "fat app" consisting of several individual "tools" - that could be apps by themselves - with specific purposes. However, these tools, which are actually different spaces, or modules within *WeInvestigate*, are only as purposeful as their curricular context allows them to be.  The design of the *WeInvestigate* learning environment – the modules and the curricular context - therefore, was synergistic. In designing *WeInvestigate*, we expected that the written curriculum would leverage the unique opportunities provided by the technological features, particularly the synchronous collaboration

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within the modules, to support student learning and collaboration. Thus, the design of the written curricular unit was influenced by the technological possibilities. Additionally, in order to develop and be able to implement  - via this technology  - a curricular unit founded on research-based collaboration design principles, the capabilities of the technology, too, had to be modified and in some cases extended beyond what it had originally been designed for. Thus, the design of the written science curriculum embedded within the *WeInvestigate* app was both influenced by the synchronous collaboration modules, and also informed the final form and use of those modules.

### 3.1.1. Three-dimensional learning.

*Science content.* We began the design of the curricular unit to be embedded in *WeInvestigate* by first deciding what science content would be the focus of teaching and learning for this study. As this was not necessarily meant to be a study of a particular curriculum, or of students learning particular content, we wanted to include content for which the conceptual terrain – including students' learning and challenges with those concepts – was well studied. The teacher recruited to participate in the study had initially suggested to us "any physical science topics" because she lacked well-written, accessible text through which to engage her students in this content, and the resources to tackle the abstractness of the content. With this in mind, we undertook an extensive review of the science education literature. We found physical science content – more specifically, describing matter and changes in matter, both in terms of their macroscopic properties, and their nanoscopic structure and behavior – to be extremely well-studied content (e.g., Smith et al., 2006; Berkheimer et al., 1990; Andersson, 1990). Student alternative conceptions and challenges with the content are well documented (e.g., Osborne & Cosgrove, 1983; Novick & Nussbaum, 1978, 1981). As a result of so many studies, there are a

number of evidence-based learning progressions, learning performances, instructional strategies, and activities designed to teach this content (e.g., Smith et al., 2006; Lee et al, 1993).  Thus, after careful consideration of the science education literature and in consultation with the teacher-participant, the science topics integrated into *WeInvestigate* focused on the following concepts: the particle nature of matter, describing matter as solid, liquid, or gas (both macro- and nano-level behavior and structure), and changes in states of matter (again, both macro- and nano-level), including how changes in energy affect changes in matter.

Cross-referencing our choice of content with both the standards for the state in which the study took place, as well as the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), we found the following matching performance expectations (from NGSS):

5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.
5-PS1-3. Make observations and measurements to identify materials based on their properties.
MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

***Science practice and cross-cutting concepts.*** For at least the past two decades, reforms in science education have focused on learning science content through participation in science practices (Abd-El-Khalick et al., 2004; Duschl, Schweingruber, & Shouse, 2007).  Participation in science practices, such as planning and carrying out an investigation, and analyzing and interpreting data, involves both the engagement in that work, and the meta-knowledge about why that practice supports the work of scientists more broadly.  Both the *Framework* (NRC, 2012) and NGSS (NGSS Lead States, 2013) have evolved from these years of research and calls for increased integration of science content, and practices. To ensure that the *WeInvestigate* learning environment was in line with these current reforms, we sought to engage students in learning about the nature of science and scientific practices in conjunction with learning science content and crosscutting concepts.

The scientific practice of developing and using models to explain phenomena was integrated into the *WeInvestigate* curriculum as the primary means through which to engage students in learning the science content described above. We chose this practice for several reasons. First, the practice of modeling is one of the eight core scientific practices identified in the *Framework* (NRC, 2012), and heavily integrated into the performance expectations in NGSS (NGSS Lead States, 2013) beginning early in middle school. Two of the three performance expectations identified in the previous section begin with "Develop a model." Also, like the content, scientific modeling is well studied as a cornerstone of other science practices (e.g., Lehrer & Schauble, 2010; Schwarz et al., 2009; Windschitl et al., 2008; Harrison & Treagust, 1998; Grosslight et al., 1991). There is also quite a bit of research that recommends engaging students in scientific modeling as a way for them to better understand physical science content, particularly the chemistry content chosen for the *WeInvestigate* curriculum (e.g., Akaygun & Jones, 2013; Chang et al., 2010; Wu et al., 2001). Finally, research also suggests that enriching students' conceptions of the nature of models may facilitate student learning from models (e.g., Snir et al., 1988). Thus, built into the *WeInvestigate* text were repeated instances of explicit metamodeling instruction on the nature of models and modeling as a scientific practice. An example of this from *WeInvestigate* is in Figure 3.1 below.

Models also help scientists communicate their ideas, understand processes, and make predictions because models help make something simpler or easier to see. Every model is like the real thing in some ways and different from the real thing in some ways. Different models of the same thing can be useful in different ways. Scientists use models to show their ideas and explain how things work. Once you have created your model (your drawing), you will use it to communicate your ideas to your classmates. You will also eventually use this model to make predictions and explanations. (*WeInvestigate* Lesson 3, Page 6)

*Figure 3.1.* An excerpt of text from *WeInvestigate* that shows explicit metamodeling instruction.

The content instruction in *WeInvestigate* primarily included discussion of the crosscutting concept of Structure and Function, found in the *Framework* (NRC, 2012) and NGSS (NGSS Lead States, 2013). *WeInvestigate* emphasized the differences between the world at the "macro-

level" and the world at the "nano- or molecular-level." In particular, students were asked to use their knowledge of the behavior and properties of objects at the macro level to hypothesize what they think the structure of that material would be at the nano level. Conversely, once students gained more awareness of the structure of materials at the nano level, they were asked to explain the behavior and properties of objects at the macro level.

**3.1.2. Curricular unit adaptation.** Because the curricular context is very important for student learning, using research-based materials with documented evidence of their effectiveness provided a solid foundation upon which to build a unit for integration into the *WeInvestigate* technology, and to support a study where the focus could be more on aspects of student engagement through the technology, and less on the effectiveness of the written curriculum. Therefore, instructional materials from a variety of sources were incorporated into the *WeInvestigate* curricular unit. The design team chose to primarily use the Investigating and Questioning our World through Science and Technology (IQWST) "Smells" unit (Krajcik et al., 2013) to provide an engaging and feasible project-based context, as well as to provide some guidance for lesson structure and activities. We chose to adapt pieces of an IQWST unit because it is an NSF-sponsored middle school science curriculum aimed at having students develop an understanding of both science content and the nature of science and science practices, including an emphasis on student collaboration. The Smells unit, in particular, aligned with our chosen content and practice goals. It engages students in a prolonged inquiry in a project-based and collaborative environment (Blumenfeld & Krajcik, 2006), to answer the Driving Question, "How can we smell things from a distance?" Embedding student learning in this real-world experience of smell provides a meaningful context for knowledge building (Blumenfeld & Krajcik, 2006), and supports students' collaborative participation in authentic scientific practices such as

scientific modeling (Krajcik & Merritt, 2012; Fretz et al., 2002). The Driving Question acts as an important organizing and motivational feature, and may address some of the barriers to collaboration in schools in that it grounds students' learning in their own experiences, about which all students can talk. It is a complex, open-ended but focused question, that requires exploration of several different concepts, and thus necessitates collaborative interactions, to fully answer. Through an initial anchoring experience (Cognition and Technology Group at Vanderbilt [CTBG], 1990) in which students engage in discussion around the phenomenon of smells, the class begins to form a collaborative community through the development of a common language and motivation for exploration around which the rest of the unit is built.

In addition to adopting the Driving Question, the motivational phenomenon of how we can smell something from a distance, and some of the specific activities of the IQWST Smells unit, we also incorporated into the design of *WeInvestigate* a consistent lesson structure, which we suspected might support student collaboration in that, after the first couple of lessons. It reduced the complexity of the expectations around the tasks students were asked to do (Quintana et al., 2004), because they could rely on the consistency of the lesson's expectations. For example, in general, the lessons first engaged students in observing and discussing a video of a phenomenon; co-constructing a model and explaining that phenomenon; reading some scientific text designed to support student understanding of the science concepts related to the phenomenon; revising their models or explanations as necessary based on the reading; and answering some follow-up or reflection questions. A more detailed overview of the progression of lessons in the unit is provided later in this paper.

**3.1.3. Science texts and representations.** In this study, the teacher-participant's primary focus in her science classroom was on exposing her students to, and helping them interpret,

informational text.  She came into this study requesting that we include age-appropriate science

texts in our final product.  She also desired resources through which to help her students

visualize the abstract nano-level content. Thus, we sought to supplement our adapted IQWST

lessons with additional scientific written text and representations.  Written texts came from a

variety of web-based sources, such as *Discovery Kids, How Stuff Works*, and the Public

Broadcasting Service (*PBS*). Paper-based sources of texts included excerpts from trade books,

such as the *Do It Yourself* and *Science Around Us* series, as well as from other research-based

science curricula such as the *Seeds of Science/Roots of Reading* units.  A content expert reviewed

the texts and made suggestions for revisions - to ensure that the excerpts chosen from these texts

were age-appropriate yet challenging and scientifically accurate. Representations meant to help

students visualize and interact with the abstract content of the unit came from the Concord

Consortium and the American Chemical Society (ACS) in the form of animations and

simulations.

## 3.2.  The Technology

The *WeInvestigate* digital learning environment is an application ("app") for use on a

tablet computer.  An "app," as recently defined by Garner and Davis (2013), is a structured

solution to a discrete problem. The *WeInvestigate* app, similar to the other computer-based

programs mentioned previously, goes beyond this idea of a "discrete" solution to an educational

problem, as it comprises curricular and technological features based on decades of research on

how people learn (e.g., Bransford et al., 2000).  In colloquial terms, it is a  "fat app" - it is

comprised of several applications, which are "collabrified" - WeModel (a drawing

app), WeWrite (a text editor), WeRead (an ebook reader), WeWatch (a video player);

furthermore, it plays simulations. This is similar to environments such as BGuILE and WISE in

that there are several "tools" built into the app. Screenshots of these modules are shown in Figure 3.2. We use the term "collabrified" from this point forward to mean that the app enables multiple students to work together synchronously, while each is using his/her own tablet (Soloway, personal communication, 2013).

Figure 3.2 also shows the split-screen capability of *WeInvestigate*. Although the choice to have a split-screen design for the *WeInvestigate* app meant that the space for any individual module was at a premium, it was a purposeful decision in that we wanted to allow students to view certain modules simultaneously. Not only did we believe this would support student completion of tasks, because they could use two modules without having to flip between windows, we also hoped it would support student knowledge integration (Linn et al., 2004) across the multiple modules and tasks.

c)
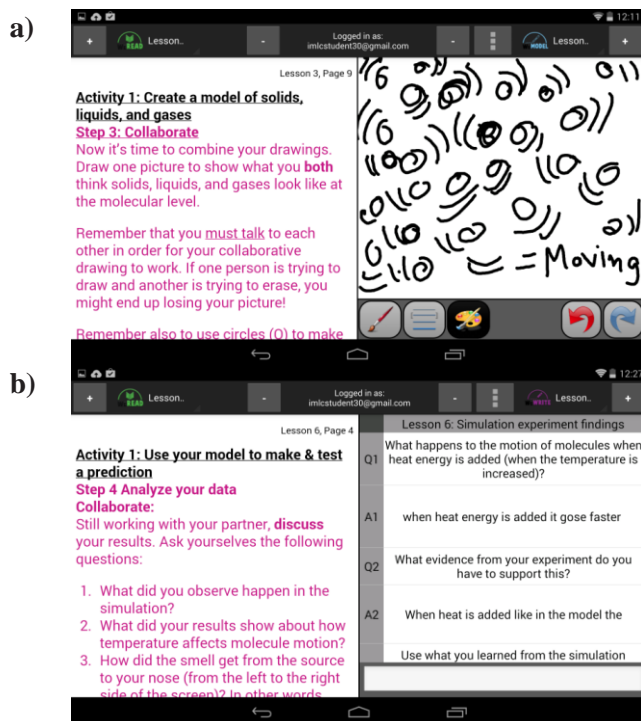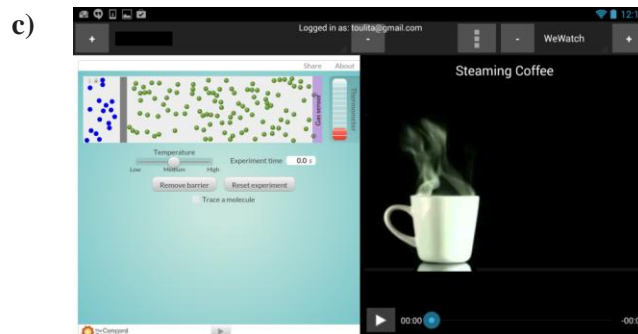
*Figure 3.2.* Screenshots of the *WeInvestigate* learning environment. a) WeRead on the left, WeModel on the right; b) WeRead on the left, WeWrite on the right; c) and interactive simulation on the left, a video clip in WeWatch on the right.

**3.2.1. "Collabrification".** Similar to all of the computer-based science learning environments on which *WeInvestigate* was based (e.g., WISE, BGuILE, Model-It), *WeInvestigate* was designed for student collaboration. Unlike these other environments, however, all of the spaces (i.e., each module), within the *WeInvestigate* app, except WeRead, were collabrified. This collabrification of *WeInvestigate* was hypothesized to be the primary built-in support for student collaboration as they engaged in modeling tasks both face-to-face and through the app. As such, investigation of this presumed affordance to effectively support student collaboration was a major goal of our work. We were most interested in examining how the collabrification functioned for students in the science classroom, the ways in which it supported their collaborative engagement in science modeling tasks, and what additional supports would be necessary in a collabrified science learning environment.

While participating in learning within the *WeInvestigate* environment, each student used his or her own tablet computer. The teacher established the expectation at the beginning of the unit that, when students worked within the *WeInvestigate* app, they would be working collaboratively with their partner to complete the lesson tasks. This expectation was reinforced in at least two concrete ways. First, the WeRead text was colored differently to signify when

students were to collaborate around the task. Second, to make collaboration within the app a conscious effort, students actively had to link their tablets together, that is, one student created a session and the other student joined that session. This linking was necessary to collabrify the modules, and students spent most of their *WeInvestigate* learning time working within these collabrified modules and WeRead. These collabrified spaces encouraged students to critique, refine, and come to consensus on ideas related to the artifacts being produced within those spaces (Linn et al., 2004).

  **3.2.2. Independent work.** Although the benefits of working collaboratively have been well documented (e.g., Brown and Campione, 1994; Hoadley & Linn, 2000; Scardamalia & Bereiter, 1996) it is also a necessary part of learning that students are given time to work independently. Because students' prior knowledge and alternative conceptions influence their learning, it is important activate and reveal this knowledge (Smith et al., 1994).  It is necessary to make individual thinking visible to promote inspection of and reflection upon one's own ideas (Linn et al., 2004). Although the bulk of the activities in *WeInvestigate* took place within the collabrified modules, the *WeInvestigate* design team purposefully included opportunities for students to work independently of their partner, such as on pre- or post-task prompts. In the spirit of the classic think-pair-share strategy (Lyman, 1987), individual "think time" (Stahl, 1994) was strategically built into lessons in *WeInvestigate* as a means of preparing students to collaborate, and strengthen their collaborative discourse. For example, in the first lesson of the unit, students were given time to construct and explain their own model for the phenomenon of smell, making their thinking visible to themselves, and positioning them to later discuss their ideas with a partner. Many lessons in *WeInvestigate* included prompts before tasks in which students independently recorded their ideas, to be later shared with their partner for the purpose of artifact

co-construction. Lessons also included prompts for students to answer independently after concluding the lesson tasks, to synthesize and internalize the ideas that were generated collaboratively during the tasks.

It was originally the intent of the team that students have an independent (i.e., un-collabrified) workspace within the app itself. However, due to technological constraints, and a presumed added layer of student confusion, it was thought best that students confine independent work to a paper workbook. Thus, for this initial iteration of the design of the *WeInvestigate* learning environment, the expectation was set up for students that work done independently occurred within the paper workbook and work done collaboratively occurred within the tablet.

**3.2.3. WeRead.** This module guided students through their work within the *WeInvestigate* environment, and many of the supports for collaborative learning were found in WeRead. The text reduced the complexity of tasks, decomposing them, by providing directions for all activities, including when to work independently or with their partner, and how to navigate between activities and modules within the app (Quintana et al, 2004). Built into the design of WeRead were several strategies based on the principles of supporting student collaboration, which were aligned with our theoretical perspective. Mentioned in the previous section, as shown in the screenshot from Lesson 1 in Figure 3.3, students were often given individual think time (Stahl, 1994) in order to support them in making their initial ideas clear to themselves first (Linn et al., 2004). Given think time, students are better positioned to later engage in a discussion with their partner around their ideas for developing a collaborative model and explanation. In the example in Figure 3.3 (Step 1) students were asked to first work individually in their *WeInvestigate* workbook to construct a model and explanation for how they think we smell something from a distance.

The direction for individual think time shown in Figure 3.3 was in black text, a simple, but purposeful, aspect of our design. The text color in WeRead was meant to signify to students when they were expected to work individually, as in Figure 3.3 which had black text, and when they were expected to work collaboratively with their partner, as in Figure 3.4, which had purple text. Also shown in Figures 3.3 and 3.4, are the navigational cues that were highlighted by the color of the text (as well as through instructions written in the text). Links were included at the bottom of each WeRead page that directed students to "Go on" (in green) to the next section, activity or other module, to "Stop" (in red) to pay attention to the teacher or be prepared to discuss with the whole class, or to navigate back to the Table of Contents[6]. Students wanting to revisit previous readings and directions could do so at any time by visiting the Table of Contents and navigating to the desired WeRead page. These colored textual cues and directions were meant to "offload nonproductive work" for students related to navigation and management throughout *WeInvestigate* (Quintana et al., 2004, p.366). We built into *WeInvestigate* as much as we were allowed by the technology supports to handle the non-salient, routine tasks, such as these navigational cues, directions, and reminders for students to collabrify their tablets (mentioned in the Collabrification section above). By doing this, we hoped to reduce the cognitive load required of students to figure out, for example, where to navigate to next, such that their focus could be more on the requirements of collaboration around the science tasks (Quintana et al., 2004).

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[6] Links did not connect modules to one another. In other words, a student could not click on a link in WeRead and have it take them to the appropriate page in WeModel. This was an anticipated challenge for app use.

In the space provided in your WeInvestigate workbook, draw a picture to show what you were thinking in your head. <u>How does a smell get from the source of the smell to your nose? Explain your drawing.</u>

<span style="color:red">Do this on your own. Your teacher will tell you when to move on to Step 2.</span>

<span style="color:green">Once your teacher says it is okay, go to Step 2.</span>

*Figure 3.3.* Screenshot from WeRead, Lesson 1, Step 1. Students are given individual "think time" to draw and explain a model of how we smell something from a distance. Directions for individual work (black); directions to stop and work (red); directions to move on to the next step (green).

To facilitate students' face-to-face sharing of their individually articulated ideas and to support possible knowledge building (Quintana et al., 2004; Linn et al., 2004), sharing protocols and question prompts were also built into WeRead. For example, as shown in the Lesson 1 screenshot in Figure 3.4a (Step 2), each student in a pair was assigned at the beginning of the unit to be "Student 1" or "Student 2." Using the sharing protocol, or script (Noroozi et al., 2012), one student was guided to share her individual work, followed by the other student using a series of questions to "check" that her partner's model included specific components (e.g., the smell, how the smell traveled). Both students were given the opportunity to share their thinking and to "check" their partner's thinking. This was followed by questions which prompted the pair to freely compare their models and explanations, looking for similarities and differences. A prompt also encouraged them to begin to think and talk about how they would "combine" their drawings into one drawing to explain how we smell from a distance. Similar prompts for students to "check" that their joint model included specific components (i.e., the nose, the source, and the smell) were included after they had finished co-constructing their model, as shown in Figure 3.5a (Step 4). Students were also encouraged to go back and revise their model if these components were not present. These supports in WeRead were designed to elicit and make clear students'

initial thinking (Linn et al., 2004) to themselves and to each other, with the intention that they would be better positioned to engage collaboratively around the model construction task to follow.

**Activity 1: Draw how you can smell something from a distance**
**Step 2: Share your ideas with your partner**
**Student 1:** Share and explain your drawing to your partner first.
**Student 2:** While your partner is sharing, ask them these questions:

1. Does the model show the actual smell?
2. Does the model show how the odor got from the source to your nose?
3. Does the model explain how we smell things from a distance?

**Then switch roles**: Student 2 shares their drawing, and Student 1 asks the questions.
**Discuss together:**

1. What is similar about your drawings?
2. What is different?
3. How can you combine both of your drawings into one drawing that explains how we smell?

When you and your partner have shared with each other, go on to Step 3.

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**(a)**

**Step 3: Draw with your partner**
Go to the **WeModel** module on the right side of your screen and open the file called **Lesson 1: Draw how we smell.**

**Student 1:** Create a session and wait for student 2 to join – be sure to tell your partner what the session number is! Click "OK" only after your partner has joined the session!
**Student 2:** Ask your partner which session number to join, and join that session.
**Collaborate:**
Now it's time to combine your drawings. Draw one picture to show what you both think happens: How does a smell get from the source of the smell to your nose?

Remember that you must talk to each other in order for your collaborative drawing to work. If one person is trying to draw and another is trying to erase, you might end up losing your picture!

When you are done with your drawing, go on to Step 4.

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**(b)**

*Figure 3.4.* Screenshots from WeRead, Lesson 1, Steps 2 and 3. (a) Students are given a scripted protocol to use for sharing their individual model and explanation. Prompts also encourage students to examine similarities and differences across their individual models, as well as to consider how they will create a single model. Text signifying student collaboration is purple. (b) The text provides navigational guidance, as well as instructions for collabrifying WeModel. Text then tells students to "collaborate" with directions for how they should do that within WeModel. Text is underlined for emphasis.

Also built into WeRead were prompts to assist students in planning and monitoring the collaborative tasks (Quintana et al., 2004; Linn et al., 2004), such as for how students should be working together within other modules in the app, such as WeModel and WeWrite. In order for students to utilize the potentially most powerful built-in support for collaboration, the synchronous collaborative feature, they had to actively collabrify modules, mentioned in the previous "Collabrification" section above. Figure 3.4b (Step 3) provides an illustration of explicit

direction for students to navigate to WeModel and "create" and "join" a session. This is also shown in Figure 3.5b (Step 5) for WeWrite. This action effectively links each student's tablet such that they are "screen sharing" WeModel and WeWrite, respectively.

The literature is still unclear about what types of prompts are most effective in supporting student collaboration. There is some evidence that prompts for students to "argue" instead of "collaborate" have produced more lasting conceptual change (Asterhan & Schwarz, 2007). There is also evidence that prompts for students to "reach agreement" rather than "persuade" have benefits as well (Garcia-Mila et al., 2013). The guidance for co-construction of a model and explanation in *WeInvestigate* contained explicit instructions for students to "collaborate," and "combine" their drawings into one, essentially telling them they had to come to consensus with their model and explanation.

The directions for collaboration often, as in the examples in Figures 3.4b and 3.5b, reminded students that they first had to "talk," and essentially coordinate what they would draw or write. The difference in directions between WeModel (Figure 3.4b) and WeWrite (3.5b) for the co-construction of the artifacts was subtle, but meaningful with respect to the differing capabilities of the two modules. The instructions for WeModel reminded students to talk to each other because if they both just started drawing independent of each other their product may not turn out well, or representative of both students' ideas. The instructions for WeWrite, on the other hand, reminded students not only that they must talk to each other first, but that only one person could write at a time, and that after they talked and decided what to write, one person should be chosen to type their response. These instructions were given for practical reasons related to the technology. WeWrite was not a fully collabrified module, as will be described in more detail in a later section. Whereas whatever actions a student took in WeModel on her tablet

would show up in WeModel immediately on her partner's tablet, in WeWrite, the student had to

hit "enter" first. This meant that only one student could type and hit enter at a time. If both

students tried to type and then hit enter, only the last entry would be visible. Thus, the

collabrified technology itself reinforced that students *had* to talk to each other, at least to

coordinate their joint artifacts, because their tablets were linked and they could not just do

whatever they wanted, independent of their partner. At the beginning of our study, it was

hypothesized that the collabrification of the modules, and the accompanying guidance and

supports built into WeRead, would support student collaboration for potential knowledge

building as they engaged in co-construction of modeling and explanation tasks.

**Step 4: Check your drawing**
1. Did you include the source of the smell in your drawing?
2. Did you include your nose in your drawing?
3. Did you represent the actual smell in your drawing?

If you need to, go back and make sure you add these things to your drawing.

Once you and your partner have a model you both like and can explain, go on to Step 5.

**Step 5: Explain your drawing**
Once you and your partner have a drawing that you both agree shows what the smell is and how it gets from the source to your nose, explain what you drew.

**Collaborate:**
Go to the **WeWrite** module on the right side of your screen and open the file called **Lesson 1: Explain your drawing.**

**Student 1:** Create a session in WeWrite and wait for student 2 to join – be sure to tell your partner what the session number is! Click "OK" only after your partner has joined the session!
**Student 2:** Ask your partner which session number to join, and join that session. You must also be in WeWrite.

Together, use your drawing to explain how the smell traveled from the source to your nose.

Remember that you must talk to each other in order for your collaborative writing to work. Only one person can type at a time! So discuss first what you will write, then choose one person to type the explanation.

When you are done explaining your drawing, flip your tablet so that the screen is **FACE DOWN** on the desk. Wait for your

*Figure 3.5.* Screenshots from WeRead, Lesson 1, Steps 4 and 5. (a) Students are given prompts to "check" their model for the presence of specific components, and to revise their model if necessary. (b) The text provides navigational guidance, as well as instructions for collabrifying WeWrite. Text then tells students to "collaborate" with directions for how they

should do that within WeWrite. Included in the text for using WeWrite is the reminder that only one student can type at a time.

**3.2.4. WeModel.** WeModel is a module that supported students working with their partner to synchronously draw and revise models, and engage collaboratively with interactive simulations[7] and animations. The WeModel module utilized the primary hypothesized collaboration support designed for *WeInvestigate*: collabrification.  Students used WeModel in almost every *WeInvestigate* lesson.  The WeModel drawing environment was intentionally made as simple as possible so as not to distract from the modeling task itself with too many features or drawing options (Quintana et al., 2004; Linn et al., 2004). With the support of the guidance and prompts in WeRead, WeModel and the simulations allowed students to engage in exploration of science concepts through their manipulation of the models (Dabbagh, 2005; Quintana et al., 2004; Linn et al., 2004). Students drew "freehand" (i.e., without preset shapes), used different colors, and erased/cleared. The simulations and animations included were meant to help support student conceptions and visualizations of nano-level phenomena, and help them bridge between nano- and macro-levels (Chang et al., 2010).  All interactions with models in WeModel were accompanied by writing in WeWrite.

**3.2.5. WeWrite.** In the WeWrite module students wrote collaboratively during tasks, often to explain models, but also to answer questions posed in WeRead.  All writing prompts came "pre-loaded" in the WeWrite module so that students did not always have to refer back to WeRead. This was intentionally done to support students' use of WeModel (or WeWatch) simultaneous with their writing in WeWrite, and in the hopes of supporting students to integrate their knowledge across these two modules , which comprised different, but connected, science practices. Almost always taking place after model construction tasks, the prompts in WeWrite

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[7] Used with permission from the Concord Consortium.

were designed to support students' articulation of their ideas for potential knowledge building, and were opportunities for students to explain and provide justification for the ideas that went into their models (Quintana et al., 2004; Linn et al., 2004). As such, the prompts were more explicitly focused on science content, and eliciting and having students explain their models in terms of that content.

It is important to note, as mentioned above, that unlike WeModel (and WeWatch), WeWrite was not an immediately synchronous module (though it was still collabrified) at the time of the study. WeWrite was perhaps not as easy to use as WeModel, which was an open, freeform drawing space with a few basic drawing tools. WeWrite took the form of a spreadsheet, with the question prompts pre-loaded into cells. Cells for which it was expected that students would answer questions were blank;  students had to first click on the blank cell, which brought up a separate text box in which students could type. Because of this technological design, which was beyond our control at the time, two students could not write simultaneously, and the non-writing student could only see what was written on her tablet when the writing student "entered" the text. It was also, unfortunately, quite easy for a student to accidentally delete the writing of her partner by "entering" new text.

**3.2.6. WeWatch.** WeWatch was a collabrified video watching space in *WeInvestigate*. The WeWatch module enabled students to access short (5-30 second) videos meant to illustrate, or provide examples of, different phenomena (Dabbagh, 2005).  As with most of the modules, students watched videos collaboratively. The videos did not have sound, were intentionally short, and could be watched as many times as necessary. Designed to be used in conjunction with the guidance and prompts in WeRead, it was through WeWatch that students most often gained their initial exposure to, and made observations about, specific phenomena for which they would

construct a model. For example, in Figure 3.6 a screenshot from Lesson 7 shows how WeWatch (right side) can be opened simultaneously with WeRead (left side). In WeRead are the specific question prompts to guide students' observations of a bromine evaporation video clip. The questions are also intended to support students' initial discussion around what they think is happening to the bromine at the molecular level so that the change they observe in the video occurs.



*Figure 3.6.* Screenshot from Lesson 7 shows how WeWatch (right side) can be opened simultaneously with WeRead (left side). In WeRead are the specific question prompts to guide students' observations of a bromine evaporation video clip.

## 3.3. The Teacher Guide

We began the design of *WeInvestigate*, including the teacher's guide, with a classroom-centered approach (e.g., Loh et al., 1998; Smith & Reiser, 1998; Reiser et al., 2001), in that the technological tools, written curricular unit, and the supports embedded in the app were designed

to meet the needs of individuals, pairs of students, and the teacher. The design also considered the challenges and opportunities provided by the classroom in which we conducted our study. Given that the existing work practices of the study classroom were quite traditional (i.e., teacher-directed, textbook-based, with little student collaboration) and that the pedagogy implicit in the app was quite different, we sought to explore the degree to which the app worked to "disrupt" (Christensen, Horn, & Johnson, 2008; Sharples, 2003) the traditional classroom structure by engaging students in exploring real-world phenomena through collaborative modeling-based endeavors to learn and do science.

The teacher's guide was designed to support our teacher-participant's enactment of science instruction with the *WeInvestigate* app. The guide included quite a bit of support (Ball & Cohen, 1996; Davis & Krajcik, 2005) for the enactment of *WeInvestigate*, given what we know about the challenges teachers face when enacting project-based curricula (Fishman, Penuel, & Yamaguchi, 2006; Penuel & Means, 2004; Carlsen, 1991, 1993; Songer, Lee, & Kam, 2002), when integrating technology-based instruction (Baylor & Ritchie, 2002; Mumtaz, 2000; Mistler-Jackson & Songer, 2000; White & Frederiksen, 1998), and also based on what we knew about our teacher-participant[8]. Specifically, our teacher, Ms. Jones[9], ran a very teacher-directed, structured, traditional textbook-based classroom, with very few hands-on activities, and very little student collaboration and technology use.

Consistent with our theoretical approach, as reflected in the teacher's guide, we anticipated that the primary roles our teacher-participant would play were as a guide and as support for students as they progressed collaboratively through the learning activities. We expected the teacher to take a more passive, though no less important, role with respect to

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[8] However, the teacher did not receive any professional development on *WeInvestigate*. This was, perhaps, a limitation in our study as well as in our teacher participant's ability to effectively implement *WeInvestigate*.
[9] A pseudonym

leading the class through activities, taking a "backseat" while allowing students to wrestle with challenging concepts. The teacher role would be to ensure the coherence in the content by revisiting the Driving Question, and helping students make connections between the science concepts and the smelling phenomenon.  The teacher's guide included recommendations about how to support students' small group work, where to stop students' small group work and engage in whole-class discussion and synthesis of ideas, and reminders related to technology management (e.g., suggestions to give students about which side of the screen on which to open which module). The guide also included strategies to support whole-class discussions, as well as strategies to support students' paired discourse. For instance, we included sample questions and probes to help teachers support students in making connections between the learning tasks and Driving Question.

## 3.4.  Unit Overview

In addition to the collaboration design principles built into *WeInvestigate* generally, as described in the preceding sections, the design of the unit itself, adapted from the IQWST Smells unit, was meant to foster and support student collaboration through science practices in several ways.  The consistent lesson structure reduced the complexity of the lessons by supporting students in knowing, after the first couple of lessons, what would always be expected of them (Quintana et al., 2004). In general, the lessons followed a consistent structure of:  (a) engaging students in observing and discussing a video of a  phenomenon; (b) co-constructing a model and explaining that phenomenon; (c) reading some scientific text designed to support their understanding of the science concepts related to the phenomenon; (d) revising their models or explanations as necessary based on the reading; and (e) answering some follow-up or reflection question. Similarly, the progression of the unit from lesson to lesson was designed so that

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concepts built on each other and carefully guided students, over the course of the roughly five week unit, toward a more complete answer to the Driving Question and explanation of the smell phenomenon anchoring the unit. Lessons in the unit also contained a focus question, for instance, "How does a smell get into the air?" and, "What makes something frozen?" These questions, which guide the lesson tasks, and the Driving Question for the unit, are initially open-ended, and complex enough to require multiple minds thinking, figuring out, and explaining,  and thus compelling collaborative effort.

A more detailed overview of the unit progression and performance expectations is presented here to illustrate how the different components of *WeInvestigate* were assembled to support student collaboration and knowledge building.

The unit began with an anchoring experience (Cognition and Technology Group at Vanderbilt [CTGV], 1990) in which students were confronted with some strong smells, and some questions were raised about the phenomenon of smelling, specifically about how the students thought they could smell those items, especially the ones located on the other side of the classroom. This discussion led into the introduction of the Driving Question: "How can I smell things from a distance?" which was used to frame all of the learning that occurred throughout the unit (Krajcik et al., 2008; Blumenfeld et al., 1991). Students were then challenged to draw a model and use that model to explain how they could smell things from a distance, revealing their prior conceptions (Linn et al., 2004).

Students then observed matter in action. Specifically, they observed videos of solids, liquids, and gases and described matter based on their macroscopic properties. These observations and descriptions allowed them to be able to generate initial models showing what they thought solids, liquids, and gases might look like at a molecular level (having already some

prior knowledge about molecules). In addition to constructing these models, students read and discussed the nature of scientific models, and how scientists use models in their work, relating to their own purpose for constructing models throughout the unit. After reading more about nanoscopic properties (e.g., structure and behavior of molecules) of solids, liquids, and gases, students revised their initial models to include this new information.  Each pair of students had some model that showed their idea, based on some science content, about the molecular structure of solids, liquids, and gases, which also worked to explain the macro-level behavior of matter. Having experience creating their own models, students were then poised to work with their peers and their teacher to create a class consensus model to represent solids, liquids, and gases at a molecular level. A common class model helped support a consistent and common means of representing matter, and supported a common way of talking about matter.  These class consensus models were also intended to support students' generation of mechanistic models to represent changes in matter.

Students then engaged with models in the form of computer simulations in which they learned that molecules in matter move, that they move differently in solids, liquids, and gases, and that the degree of motion has to do with the relative attraction between molecules.  With this knowledge, the class revised their consensus models. Through interaction with another computer simulation, students learned about the relationship between molecular motion and temperature, namely that increasing the temperature of a material caused molecules that comprise that material to move faster. Again, they revised their class consensus models to include this information.

With a basic understanding of molecular structure, motion, and relationships between temperature and molecular attraction, students spent several lessons developing models to

represent processes of changes in matter (e.g., evaporation, condensation). These lessons began with exposure to a phenomenon (e.g., gallium melting), after which students used the class consensus models, and then developed a model that showed the mechanism by which the change between the starting state of matter (e.g., solid) and the ending state of matter (e.g., liquid) occurred.  With these models students explained how the phenomenon occurred (e.g., how gallium melted).

The unit ended similarly to how it began. Students revisited the Driving Question, and created new models to explain how we can smell things from a distance, this time incorporating the knowledge gained throughout the unit about how matter changes, and what causes matter to change.  Finally, students were asked to extend this knowledge to explain a new phenomenon: how someone with a peanut allergy can experience a reaction without ever touching a peanut.

**3.4.1. Performance Expectations.** To address the NGSS performance expectations in rigorous and meaningful ways in the *WeInvestigate* learning environment, we developed our own performance expectations (Krajcik, McNeill, & Reiser, 2000) for each lesson.  Mentioned previously, there has been a shift in focus in science education toward a "knowledge in use" or a practice-based view of science, articulated in the integration of content, practice, and crosscutting concepts in the NGSS performance expectations, and thus in our own performance expectations. Performance expectations identify what students should know and be able to do to demonstrate their understanding (NGSS Lead States, 2013).  They specify how knowledge is to be applied.  The performance expectations created for each lesson in the unit are listed in Table 3.1 below.  Also included in this table is a more detailed description of the activities in that lesson, including how that task was meant to be carried out (independently, collaboratively in pairs, whole class), and in which *WeInvestigate* module the task was done.

Table 3.1.

*Performance expectations for the WeInvestigate curriculum*

| Performance Expectation(s) | Lesson Details |
|---|---|
| Lesson 1: Students [independently and collaboratively in pairs] develop and use a model to explain their initial ideas about a) what an odor is made up of, and b) how the odor moves from a source to their noses.[10] | • Students work independently in their workbook to construct (draw) and explain a model that shows their thinking about how we smell things from a distance. <br><br>• Using a sharing protocol (found in *WeRead*), student pairs share their models and explanations, then discuss similarities and differences, and decide how to construct a single model of how we smell. <br><br>• Student pairs work to construct (draw) a single model and written explanation. Model drawing occurs in *WeModel* and the written explanation is in *WeWrite*. |
| Lesson 2: Students use science text, images, and videos to describe matter as solid, liquid, and gas based on macroscopic properties. | • Students collaboratively read (in *WeRead*) about matter, then about data and what constitutes evidence. <br><br>• Using a question protocol (in *WeRead*) student pairs observe and discuss videos of different states of matter "in action" in *WeWatch*. <br><br>• After they watch the videos and discuss answers to questions verbally, student pairs answer questions about the videos formally and collaboratively in *WeWrite*. <br><br>• Students read about (*WeRead*) and discuss the states of matter. From these readings they are encouraged to revise their previous pair-writing (in *WeWrite*). <br><br>• As an extension, students individually answer questions about new phenomena in their workbook. This is followed by a pair-share with writing (in *WeWrite*) and subsequent whole-class discussion. |
| Lesson 3: Students use descriptions of nanoscopic properties of matter, found in science texts, to construct and then revise models of the molecular structure of solids, liquids, and gases. | • Students read as a whole class about matter at the nano-level. They also read about and discuss model use in science. <br><br>• In their workbook, students individually draw models of what they think the structure of solids, liquids, and gases look like at a molecular level. <br><br>• Using a sharing protocol (in *WeRead*), student pairs share their models, then discuss similarities and differences, including how to construct a single model for each state of matter. <br><br>• Student pairs work collaboratively to construct (draw) a single model for each state of matter (in *WeModel*). <br><br>• After being guided by their teacher through readings about the nanoscopic properties of each state of matter (*WeRead*), student pairs again work collaboratively to revise their models of solids, liquids, and gases at the molecular level (in *WeModel*). |
| Lesson 4: Students participate in teacher-mediated discussion to develop a class consensus model of the molecular structure of solids, liquids, and gases that helps explain both macroscopic and nanoscopic properties of matter. | • With teacher guidance, the whole class constructs a consensus model for solids, liquids, and gases at the molecular level. <br><br>• Students individually answer a follow-up question in their workbook. |
| Lesson 5: Students use previously developed molecular models (in the form of computer simulations) to explain the | • In pairs, students observe computer simulations showing a representation of the motion of molecules in solids, liquids, and |

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[10] Adapted from IQWST Smells unit

| | |
|---|---|
| macroscopic behavior of solids, liquids, and gases.<br><br>Students use information gleaned from these models to revise their class consensus models so that they better represent how molecules move in solids, liquids, and gases. | gases in *WeModel*. While they do this they collaboratively answer questions in *WeWrite*.<br>• After working with their partner to explore the motion of molecules in solids, liquids, and gases, each student independently answers some follow-up questions in their workbook.<br>• Students participate in a teacher-mediated whole-class discussion to revise their class consensus models, based on what they learned by interacting with the simulations. |
| <u>Lesson 6</u>: Students use previously developed models to make predictions and test their predictions about how adding (and removing) energy (in this case, thermal energy) to a system of molecules will affect how the molecules move.<br><br>Students use a model (in the form of a simulation) to make predictions about and then explain other phenomena (e.g., food coloring in hot water vs. cold water). | • Students individually make a prediction in their workbook about what happens to the molecules in a material when it is heated? Cooled?<br>• Using a sharing protocol (in *WeRead*), student pairs share then discuss their predictions with each other.<br>• Student pairs work collaboratively in *WeModel* to test their predictions using another model (in the form of a computer simulation).<br>• Using a question protocol (in *WeRead*) student pairs verbally discuss the simulation.<br>• In *WeWrite* student pairs formally write their answers to questions about the simulation.<br>• Individually, students make a prediction about what will happen in a demonstration with food coloring placed in hot and cold water.<br>• An optional extension activity has students again working collaboratively in pairs to observe a single video in *WeWatch*, during which there are guiding questions (in *WeRead*) for students to discuss, followed by questions (in *WeWrite*) to answer collaboratively. |
| Lessons 7-11: Students develop a model to explain changes in states of matter at the molecular level.[5]<br><br>Students use a model and text to explain changes in states of matter at the molecular level.[5,11] | • Students read as a whole class (in *WeRead*) some introductory material.<br>• Student pairs observe a video (in *WeWatch*) as a lead-in to the specific change of state (e.g., bromine evaporation).<br>• Using a sharing protocol (in *WeRead*) student pairs discuss what they observe in the video.<br>• After this initial exposure, student pairs must use the class consensus models, information from the text, and what they know, to collaboratively develop a model (in *WeModel*) for the change of state being explored. Prompts are provided (in *WeRead*) to guide students through this more involved process-model.<br>• With their model done, student pairs use their model to collaboratively explain in writing (*WeWrite*) the phenomenon observed in the lead-in video.<br>• For Lessons 7 & 8 only (evaporation & condensation), which are generally more challenging phase changes for students to envision, student pairs have additional exposure to other models (computer simulations). The pairs observe the simulations (in *WeModel*) and discuss and collaboratively write (in *WeWrite*) the answers to guiding questions provided in *WeRead*.<br>• Each modeling activity in Lessons 7-11 is followed by scientific text about the change of state, which the teacher guides the whole |

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[11] Except for the noted exceptions for lessons 7 & 8, lessons 7-11 (each representing a different phase change) follow the same lesson format, so have been included here together.

| | |
|---|---|
| | class through.<br>• The teacher leads the students in a whole class development of a consensus model and discussion about the specific change of state.<br>• Each lesson concludes with students independently answering follow-up questions (in workbook). |
| Lesson 12: Students use the molecular model of matter to explain changes in states of matter, and to explain how we can smell things from a distance.[4]<br><br>Students use the molecular model of matter to explain a new phenomenon. [4] | • Students work independently in their workbook to construct (draw) and explain a model that shows their thinking about how we smell things from a distance.<br>• Using a sharing protocol (found in *WeRead*), student pairs share their models and explanations, then discuss similarities and differences, and decide how to construct a single model of how we smell.<br>• Student pairs work to construct (draw) a single model and written explanation. Model drawing occurs in *WeModel* and the written explanation is in *WeWrite*.<br>• Student pairs read about (in *WeRead*) then explain (in *WeWrite*) a new phenomenon: how can a person with a peanut allergy show a reaction when they never touch a peanut? |

## 4. Summary

The purpose of this paper was to articulate the design rationale and development of a mobile app-based learning environment to support student collaboration around science content and modeling. We began by describing the theoretical argument and our perspective of collaboration in science, on which our design was based. Grounded broadly in social constructivism, our design work was based on the notion that students should engage collaboratively around science practices because it is authentic to the work of scientists, and it helps to enculturate students into more deeply learning science content. Following this, the collaboration design principles described in this paper were considered to be situated within the context of the science practices around which students were collaborating. We then discussed the characteristics of effective collaboration, and the barriers to effective collaboration in schools. *WeInvestigate* was presented as a possibility of how collaboration and technology (PCAST, 2010) can be integrated and used to address current reform efforts in science (NGSS Lead States, 2013), and to confront some of the barriers to effective collaboration in school science.

In describing each component of the *WeInvestigate* learning environment (the technology, the designed student curriculum, and the teacher's guide), we tried to be mindful about the design choices we made, drawing on the published literature, and including concrete examples of some designed supports for collaboration as they are manifest in *WeInvestigate*. In particular, our design of collaborative supports was centered around students' use of the collabrified capability of the technology, which was assumed to be the main affordance for student collaboration in *WeInvestigate*. In Table 3.2 we summarize the collaborative design principles considered, as well as how the principle was employed, in the design of the *WeInvestigate* learning environment.

Table 3.2

*Science collaboration design principles used in WeInvestigate*

| Science collaboration design principles | *WeInvestigate* example |
|---|---|
| Engage students in epistemic artifact creation to advance knowledge (StereIny, 2005) | Students co-construct models (WeModel) and explanations (WeWrite) |
| Engage students in doing authentic science in meaningful contexts. (e.g., Brown et al., 1989) | Students mirror the work of scientists by engaging primarily in the practice of developing and using models. They do this within the larger context of the IQWST Smells unit, to explore the phenomenon of smell and answer, "How can we smell things from a distance?" |
| Design tasks that are appropriately complex, open-ended, and meaningful for students. (e.g., Blumenfeld et al., 1996) | The driving question, and lesson questions provide a context for students to engage in the lesson tasks. The lesson tasks, particularly the modeling and explanations are more open-ended, and complex, and contribute to answering the driving question. |
| Make collaboration an explicit, conscious effort for students. | WeRead contains different colored text to communicate to students when they should be working alone or working with their partner, in addition to having instructions to "collaborate." Students had to actively create/join sessions in each module to link their tablets. |
| Provide opportunities for students to make their thinking visible (Linn et al., 2004), to better position them to engage in discussion with their partner around their ideas. | Students use prompts and scripts included in WeRead (and workbook); have individual think time prior to engaging in paired tasks; and have initial exposure with partner to phenomena through videos, where there is discussion to elicit both students' thinking. |
| Provide opportunities for students to engage in negotiation and consensus-building around each other's ideas around making predictions, constructing models of, and explaining, phenomena (Teasley, 1997). | Directions, prompts, and scripts were provided (WeRead) for students to make predictions, co-construct models and explanations. Scripts and prompts (WeRead) guide students to examine similarities and differences in their thinking. Students are instructed in the text to collaborate around constructing a single model, and |

| | single explanation of a phenomenon. WeModel and WeWrite are collabrified, such that the product belongs to both students, and neither student can "get away with" a contribution that was not explicitly or implicitly agreed upon. |
| --- | --- |
| Provide opportunities for students to make connections between science concepts and practices. (NRC, 2012) | WeInvestigate allows for simultaneous use of multiple modules. Students are told to use their models to explain observations of phenomena. Students must connect their learning throughout the unit to model and explain the smelling phenomenon. |
| Provide reminders and guidance to facilitate students' productive planning, monitoring, and sensemaking. (Quintana et al., 2004; Linn et al., 2004). | Students use directions, prompts, and scripts (WeRead) which remind students to "talk" and "collaborate" on tasks; to support coordination of the task; to construct and "check" models; and to guide students to explain their model (WeModel) in (WeWrite). |
| Provide support for students to have joint attention to a shared representation. (Dabbagh, 2005; Barron, 2003; Suthers, 2005). | The collabrification of WeModel, WeWrite, WeWatch allows students to share their screen while each on his/her own tablet. |
| Automatically handle nonsalient, routine tasks for students. (Quintana et al., 2004) | WeInvestigate contains lessons that follow a consistent structure/pattern; navigational cues for other modules, and links to other parts of WeRead; Table of Contents in WeRead; and pre-named files in WeWrite, WeModel, and WeWatch. |
| Provide structure for complex tasks and functionality. (Quintana et al., 2004) | Ease of use of the app was supported in the design of WeModel, for example, because the choice of drawing tools was purposefully limited so as not to overwhelm students with choices. |

Although much of our design was purposeful, and built on the design principles of previous technological and paper-based learning environments, we realize also the limitations in some aspects of our design. Some of these limitations were beyond our control, and dependent upon the capabilities of the technology at the time of our study. For example, the fact that WeWrite was not immediately synchronous, as WeModel was, could not be avoided in this iteration of design. We also viewed as a limitation the fact that all of the key text, including the bulk of our designed supports, had to be in WeRead, rather than "outsourced" to the modules where, for instance, the directions or question prompts would make more sense. Additionally, while professional development to enhance the teachers' efforts engaging students in project-based instruction would have been desirable, there were constraints on the teacher-participant's time. Instead, we provided educative supports (e.g., Davis & Krajcik, 2005) for teaching with

*WeInvestigate*. In addition, members of the research team were present in her classroom every day of implementation to assist with the technology and provide nominal instructional support.

Perhaps implicit in our approach to the design of WeInvestigate was somewhat of a "booster" perspective (Bigum, 1998) relative to the use of technology in science teaching and learning. That is, we positioned WeInvestigate as a learning technology – a device students learn with, learn through, and to some extent learn about (Bigum, 1998). Further, we also maintain the view that technologies possess the capacity to support and improve the learning that occurs in science classrooms when used transformatively (e.g., Collins, 1991; McCormick & Scrimshaw, 2001; Pea & Gomez, 1992). However, we should also point out that we did not consider, nor did we design WeInvestigate as a panacea that would solve the challenges of collaboration in school science classrooms. Nor did we enter into our design of an entire system of instruction – curricular unit, readings, and activities – having fully embraced the notion of an "all-inclusive" type of science app. Rather, given that technology is very much already a part of our everyday lives, is becoming increasingly utilized in schools for teaching and learning, and some developers are targeting mobile technologies in particular for their products, we felt the need to approach both the design and subsequent study of WeInvestigate with a degree of "optimistic skepticism." This perspective is manifest in Chapter 4, which elucidates the findings of our pilot study of WeInvestigate; specifically, our examination of the ways in which the designed supports described in this paper are hypothesized to have contributed to the various student outcomes we observed.

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**CHAPTER IV**

**Investigating the "collabrified" use of an app to engage 6th grade students in model construction and model-based explanations**

## 1. Introduction

The ability to effectively collaborate to accomplish tasks and solve problems is a necessary skill to have in our global society. The intellectual demands and complexities of modern adult life - perhaps instigated by technological advances and our growing attachment to and reliance on technology - are many, varied, and subject to rapid change (Kuhn, 2015). Many of the demands of adult life are encountered in collaborative contexts. In order to be "21st century ready," therefore, young people must gain competence in, and be comfortable with, working collaboratively to address problems and meet objectives that are unique to life today. This importance of collaboration in our society is reflected in what we expect for our students in schools. Also reflected in schools is the public demand for technology, and these demands have led to increased popularity in the use of mobile devices in K-12 educational settings (Banister, 2010). Thus, the importance of technology in our society has influenced a desire - perhaps even a necessity - for technology use in schools. Given the emphasis in our society on collaboration and technology use, "technology-rich collaboration" has been identified as a 21st-century skill for students to master (NRC, 2010; P21 December 2009).

Further, collaboration and technology use are fundamental to the work of many professionals, and, specifically for the purposes of this paper, to the work of scientists. Collaboration is necessary to advance scientific knowledge (NRC, 2012). Though new ideas may be developed individually or as a group, the theories, models, and methods – the things that constitute the norms and knowledge of science – are developed collaboratively by scientists working together over extended periods of time. New technologies have not only advanced the capabilities of scientists in data collection and representation, modeling, etc., new technologies have also extended the collaborative practices of scientists, allowing for instant, synchronous, global communication, not only with other scientists, but in cross-disciplinary endeavors, as well as in communication with lay audiences (NRC, 2012). Because it is expected that students will be learning science through practice, authentic science in school will require students engaging collaboratively, and using technology in similar ways, as articulated through ambitious reform efforts such as the *K-12 Frameworks for Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013).

As mobile technologies grow ever abundant in our society, more education contexts are investing in mobile technology to support teaching and learning (e.g., Roscorla, 2010). Therefore, the need for development of effective learning environments within these technological contexts increases. Although a wide variety of apps for use on mobile devices, such as tablets, have been developed specifically for educational purposes, and many curriculum developers see tablets as the next frontier for their products, there have not yet been many K-12 research studies on the functionality and effectiveness of apps, particularly science apps, for student learning (see e.g., Enriquez, 2010; Chen et al., 2010 for college-level studies). Most educational apps involve students' consumption of content, rather than the creation of  - or collaboration around  - that

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content (Murray & Olcese, 2011). Thus, there is an increased need for empirical research on the educational effectiveness of app-based learning environments, especially for our purposes as science educators, on apps for use with tablet devices that are meant to engage students in the kind of ambitious depiction of science instruction that is captured in current reforms (NGSS Lead States, 2013; NRC, 2012).

In response to calls for the integration of collaboration and technology, particularly mobile technologies (PCAST, 2010), in schools, and to address current ambitious science reform efforts (NGSS Lead States, 2013; NRC, 2012) that advocate for learning science through the engagement in science practices to explain phenomena and solve problems, we designed an app-based K-12 collaborative science learning environment, called *WeInvestigate*. Further, to address the need for more studies on K-12 students' learning and collaboration with app-based mobile learning environments we studied its collaborative use in a sixth grade classroom. The details of the design of *WeInvestigate*, including the features designed to support students' collaborative engagement in science practices through the learning environment, were elucidated in Chapter 3. The purpose of this paper is to report the findings of a pilot classroom study of students' synchronous and face-to-face collaboration as they engaged in constructing models and model-based explanations via *WeInvestigate*. We also hypothesize the impact the design principles described in Chapter 3 had on students' collaborative engagement in these science practices through the app. Lastly, we discuss the implications of this work for the future design and research of *WeInvestigate*, and similar educational technologies.

The *WeInvestigate* digital learning environment is an application ("app") for use on a tablet computer, designed to support students' collaborative engagement in learning science content and practices within a real-world context. In colloquial terms, it is a "fat app" - it is

comprised of several applications, which are "collabrified" - WeModel (a drawing app), WeWrite (a text editor), WeRead (an ebook reader), WeWatch (a video player); furthermore, it plays simulations. Screenshots of all of these modules can be found in Chapter 3. We use the term "collabrified" to mean that the app enables multiple students to work together synchronously, while each is on his/her own tablet. [See Chapter 3 for a complete description of this environment.]

## 2. Theoretical Framework

In this study, we adopted an overall social constructivist approach to learning, and student collaboration, which we defined as a process of knowledge building, or shared meaning construction (Scardamalia & Bereiter, 1994; Brown & Campione, 1994), or more specifically as a "coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p. 70). The social-constructivist paradigm maintains that knowledge is socially constructed, and that learners should be involved in a process of collaborative knowledge construction to achieve conceptual change (Vygotsky, 1978).

Our approach is also grounded further in a situated cognition perspective, which reinforces our assertion that students should engage collaboratively because it is authentic to the work of scientists, and to engage in this practice of science helps to enculturate students into more deeply learning science content (Brown, 1995). Developing a deep understanding of science as a social enterprise, as current reforms suggest, entails engaging students socially in the practices of science. Engaging in collaborative discourse based in science practice may enable students to develop deeper disciplinary conceptual understandings (e.g, Brown, 1995; Von Aufschnaiter et al., 2007; Zohar & Nemet, 2002).

Developers of learning environments often assume that any social interaction between students is collaborative, and has benefits for learning, however this is not necessarily the case, especially in a digitally-based learning environment (Lehtinen, 2003). Embedded in the design of the *WeInvestigate* app, was the stance that technology provides the facilitative infrastructure to support collaborative knowledge building discourse, both situated in the collabrified technology, as well as through face-to-face communication. Both the collabrified nature of the *WeInvestigate* app, and the design of the written curriculum, which engaged students in model construction and model-based explanation tasks, necessitated student interactions during our study. What remained to be seen, however, was the extent to which these interactions could be called "collaborative," and the impact the collabrified learning environment and additional designed supports had on the effectiveness of students' collaboration.

## 3. Methods

Given the purpose and social constructivist perspective of our study, qualitative and quantitative methods embedded within a comparative case study (Merriam, 1998) were used. A case study design was chosen for its value examining meaning in context; thus, this study is both descriptive and interpretive in nature (Merriam, 1998). Knowledge gleaned from cases is driven and developed by reader interpretation to the extent that that readers bring their own knowledge and experiences to each case (Merriam, 1998). Therefore, the cases were created, and cross-case analyses were conducted to contribute new knowledge to the field for readers to use in building their own generalizations. A more detailed treatment of the research methods and analytical techniques used to yield the findings in this paper can be found in Chapter 2 (Manuscript 1).

### 3.1 Participants

The reader will recall from Chapter 2 that the study was conducted in one sixth-grade classroom, situated in a grade 2-6 Elementary School that has been struggling to address achievement gaps, in a small city in the Midwest. Our teacher-participant, Ms. Jones[12] identified a sample of six students (three pairs) from her class for in-depth analyses and case study development, and paired them: Mary and Hannah (Group 1), Uma and Rose (Group 2), Marcel and Quentin[13] (Group 3). All of the illustrative excerpts presented in this paper originated from Mary and Hannah, and Rose and Uma's cases, primarily for space purposes.

**3.2 Data Collection**

The primary data collected for this study included transcripts of audio recordings, which documented pairs of students' face-to-face talk as they engaged in collaborative model construction and model-based explanation tasks within *WeInvestigate*. Screenshots of the collaborative artifacts produced by the pairs of students in the "collabrified" sections of the app, as well as students' independently written work done on paper, were also collected. These data, as well as supplemental data in the form of field notes, app log files, and pre-/post-assessments, were collected over the course of twelve lessons, spanning about four weeks. Data were sampled for transcription and analysis. [See Chapter 2 for more detail regarding the data and sampling.]

**3.3 Data Analysis**

To provide some insight into the degree of collaboration, related specifically to students' transactive talk (see Chapter 3, Section 2.3) , and the content of students' discussion, quantitative content analysis (e.g., Chi, 1997) was conducted on all verbal representations of knowledge (via sampled transcripts) for the three student pairs. Transcripts were coded at the utterance level for each student's talk during small group work episodes. On-task utterances were coded according

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[12] A pseudonym
[13] All pseudonyms

to several dimensions found in the validated frameworks from Weinberger and Fischer (2006), Gijlers and de Jong (2009), and Gijlers et al., (2013), and also included inductively-generated codes. This analysis also guided the sampling of lessons and tasks for further qualitative analysis.

To more deeply characterize the collaborative knowledge building process, and whether/how it may have been supported by the collabrified technological learning environment, interaction analysis (Jordan & Henderson, 1995) was conducted on students' talk in conjunction with an analysis of their written artifacts, generated both independently and collaboratively. Case studies of the three pairs of students were created to describe the development of their socially constructed knowledge across the duration of the implementation (e.g., Merriam, 1998). Cross-case analysis was conducted to determine patterns or common themes across the pairs of students. [See Chapter 2 for more detail on these analytical techniques, with illustrative examples.]

## 4. Results and Discussion

Given the percent increase between students' pre- and post-test scores, shown in Table 4.1, we can infer that the students in this study learned many of the science concepts addressed by *WeInvestigate*. That the students could use the *WeInvestigate* app to show improvement in their content understanding is particularly notable considering that the traditional instructional context of their science class had been very teacher directed and managed, very text-based, and absent the use of much collaboration and technology. Although, as a primarily qualitative, exploratory study, we cannot make causal claims attributing this growth in content understanding entirely to students' engagement with *WeInvestigate*, it does set the stage for why we chose to do a close analysis of student interactions with each other and the app. It also shows that learning in this way, that is, through *WeInvestigate*, has promise.

This paper presents findings from a pilot study of *WeInvestigate* and makes claims related to the effectiveness of the designed features of the app, described in Chapter 3, to support student collaboration as they engaged in science practices. We sought to deeply understand the nature of students' collaborative interactions, given the presumed affordances of the *WeInvestigate* learning environment, in order to more fully characterize and understand the students' experiences.

Table 4.1.

*Pre-/Post-assessment percent increase*

| | Group 1 | | Group 2 | | Group 3[14] | | |
| | **Hannah** | **Mary** | **Uma** | **Rose** | **Marcel**[15] | **Omar** | **Quentin** |
|---|---|---|---|---|---|---|---|
| Pre-test raw score[16] | 15.5 | 12.5 | 19 | 10.5 | 15.5 | 5.5 | 7.5 |
| Post-test raw score | 23 | 24 | 24 | 23 | 19.5 | 18.5 | 17.5 |
| % increase | 48% | 92% | 26% | 119% | 26% | 236% | 133% |

The following discussion is organized around: (a) findings that may be traced to the collaboration support built into the design of *WeInvestigate*; (b) hypotheses regarding the effectiveness of that support; and  (c) implications and suggestions for improvement to that support in future iterations of *WeInvestigate*. The suggestions and implications for design may also inform the development of similar technology-based learning environments.

## 4.1.  Collabrification (and accompanying supports)

Collabrification was defined previously as enabling multiple students to work together synchronously, while each is on his/her own tablet (Soloway, personal communication, 2013). Because the collabrification feature was thought to be the central support for student collaboration built into the *WeInvestigate* learning environment, and because one of the purposes

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[14] Group 3 data is included in this paper for completeness and consistency with Chapter 2. However, the qualitative examples in this paper were taken from Groups 1 and 2.
[15] NOTE: Marcel did not complete the unit.
[16] Pre- and post-test scores are out of 25 points total.

of this study was to examine collabrification as a collaboration support I foreground students'

interactions during the use of the collabrified modules, specifically WeModel and WeWrite. I

should remind the reader that because this was not an experimental study, I cannot necessarily tie

findings to any particular support. Additionally, I cannot make generalizations from the primarily

qualitative analyses done. Instead, I present excerpts from our data, claims derived from those

and similar excerpts, and hypothesize connections to the embedded collaborative supports, as

well as possible implications of this work.

Given the foregrounding of collabrification in our design and analysis, the dominant

finding of this study, from which most of our other findings arose, was that collabrification, even

with the additional built-in supports, did not consistently support effective student collaboration.

However, we did see instances of strong student collaboration that provide encouraging evidence

of the potential of this technology, and which warrant further study. There was a great deal of

variation within and across the three focal groups with respect to the characteristics of effective

collaboration I looked for in this study.  In Chapter 3 (section 2.3), I identified several

characteristics considered to be identifiers of productive collaboration, which I looked for during

my analysis of students' interactions. In addition to higher-levels of transactive talk (i.e.,

consensus-building talk), I looked for evidence (or absence) of acknowledgement from a partner

(Dabbagh, 2005; Barron, 2003); joint attention by both students in a pair (Barron, 2003) to a

shared representation (Suthers, 2005; Schwartz, 1995); and ways in which the artifact being

created mediated (Suthers, 2005) student discourse. While I did find evidence that the

collabrification generally worked to support students' joint attention to a shared representation -

for the purposes of this study, the models and explanations - I did not often see instances of high-

level transactive talk. Table 4.2 shows that, in general, all of the three focal groups were mostly

on-task, or attentive to the task at hand. The table also shows that the percent of "no reaction" was low across the groups, which means that, when a student attempted to elicit a response of some kind from their partner, they did receive it. These codes serve as proxies to support the claim that both students in a pair were generally attentive to each other, and to the task.

Table 4.2.

*Code frequencies and percentages for on-task transactive talk for all sampled lessons.*

|  | Group 1 | | Group 2 | | Group 3 | |
|---|---|---|---|---|---|---|
| *Total utterances* | *2216* | | *1973* | | *1446* | |
| *Total on-task utterances* | *1606* | | *1814* | | *1256* | |
| *% on task* | *72.47* | | *91.94* | | *86.86* | |
| **Codes** | **Freq** | **% on-task** | **Freq** | **% on-task** | **Freq** | **% on-task** |
| Externalization | 278 | 17.31 | 262 | 14.44 | 187 | 14.89 |
| Elicitation | 281 | 17.50 | 265 | 14.61 | 218 | 17.36 |
| Quick Consensus | 174 | 10.83 | 266 | 14.66 | 99 | 7.88 |
| *Total Low-Level Trans.* | *733* | *45.64* | *793* | *43.72* | *504* | *40.13* |
| Integration Consensus | 45 | 2.80 | 61 | 3.36 | 33 | 2.63 |
| Conflict Consensus | 16 | 1.00 | 53 | 2.92 | 17 | 1.35 |
| *Total High-Level Trans.* | *61* | *3.80* | *114* | *6.28* | *50* | *3.98* |
| No reaction | 52 | 3.24 | 24 | 1.32 | 37 | 2.95 |
| *Coordinative Talk* | *562* | *34.99* | *631* | *34.79* | *366* | *29.14* |
| *Content Talk* | *196* | *12.20* | *259* | *14.28* | *99* | *7.88* |

The table also shows that students rarely engaged in high-level transactive talk, across all sampled lessons. As we will see, students struggled especially to effectively elicit their partner's ideas, press for reasoning, confront and resolve conflicts in ideas, and ask for and give content-related help (Blumenfeld et al., 1996). In addition, we did see instances in which the artifact being created mediated student talk – and in which student talk mediated the creation of the artifact – however, I did not generally see this mediation occur in ways consistent with authentic science practice, and the expectations of NGSS. These findings will be elucidated in the following sections, particularly as they are hypothesized to relate to the supports for collaboration built into the design of *WeInvestigate*, as described in Chapter 3.

## 4.2 Collabrification in WeModel vs. WeWrite

Most apps designed for education involve students' consumption of content, rather than the creation of - or collaboration around – content (Murray & Olcese, 2011). To directly address this gap, students' collaborative interactions as they engaged in both WeModel and WeWrite tasks were chosen for deeper study, specifically for these tasks' ability to illustrate students' use of the only collabrified modules in *WeInvestigate* in which students were meant to collaboratively construct artifacts of their learning. Additionally, these tasks allowed for a close examination of students' synchronous interactions, face-to-face and via the app, as they engaged in the scientific practices of developing models and model-based explanations, consistent with current reform efforts in science education (NGSS Lead States, 2013; NRC, 2012). Further, because one of the main purposes of WeRead was to guide students' use of WeModel and WeWrite, and the supports built into WeRead were integral to students' use of WeModel and WeWrite, our discussion includes relevant connections between these modules as well.

In our close examination of these modules, we found that the degree of collabrification of these two modules, which were different, resulted in different impacts on students' collaboration and their approach to tasks in these modules. Although both modules were considered collabrified, they differed in that WeModel was immediately synchronous and WeWrite was not. In other words, when one student drew on her tablet in WeModel, it would show up immediately in WeModel on her partner's tablet. By contrast, when one student typed in WeWrite, she had to "enter" the text for it to show up on her partner's tablet. These differences in the "immediacy" of the synchronicity of the modules resulted in differences in how students could interact with each other and the modules. Both students could be drawing simultaneously in WeModel, but in WeWrite, only one student could type a response to a pre-loaded question at a time. If both

students tried typing, and entering text, only the response of the student who entered text last would show up in WeWrite.

Though, in general, the *WeInvestigate* app was fairly intuitive to students, and easy to use, these differences impacted the relative "ease of use" of these modules. Drawing and editing in WeModel was very easy, and could be done by either student at any time. Simple "pencil," and "eraser" icons, as well as "clear," and "undo" buttons supported the drawing and editing. The WeWrite module actually consisted of a spreadsheet type of format in which the question prompts came preloaded into one "cell" and the answer was to be typed into another "cell." In order to respond to a prompt, the student had to first click on the blank cell, type his or her response, then hit "enter." It was possible for a student to begin typing without first having to click on the blank cell, so that when they entered their typed response, it did not appear anywhere on the screen. We provide this additional detail on the WeModel and WeWrite modules to shed light on the context and the findings that follow. More detail on these modules can be found in Chapter 3 (sections 3.2.4. and 3.2.5.).

**4.2.1. Textual guidance in WeRead.** The text in WeRead was designed (see Chapter 3) with these differences between WeModel and WeWrite in mind, and thus were written slightly differently for each module, reflective of how students should approach their work, given the affordances and limitations of the modules, particularly with respect to their collabrification capabilities. The directions and expectations for collaboration in each of these modules were initiated in Lesson 1, as the screenshots in Figure 4.1 show. The directions told students that they first "must talk," about what they would draw or write. The difference in directions between WeModel (Figure 4.1b) and WeWrite (4.1c) for the co-construction of the artifacts was subtle, but meaningful with respect to the differing capabilities of the two modules. In this example, the

instructions for WeModel reminded students to talk to each other because, if they both just

started drawing and editing independent of each other, their product might be lost. The

instructions for WeWrite, on the other hand, reminded students not only that they must talk to

each other first, but that only one person could write at a time, and that after they talked and

decided what to write, one person should be chosen to type. The subtle message in both of these

directions was that students must talk to coordinate the task for practical reasons, and not

necessarily to talk about science concepts, or reasoning for why contributions should be made.

Thus, these, and similar, directions and prompts in *WeInvestigate*, which were reflective of the

degree of collabrification and the nature of the task students were asked to do, may have

contributed to findings related to students' coordinative talk, science content talk, and high-level

transactive talk. Findings related to each of these will be discussed in turn.

**(a)**

**Activity 1: Draw how you can smell something from a distance**
**Step 2: Share your ideas with your partner**
**Student 1:** Share and explain your drawing to your partner first.
**Student 2:** While your partner is sharing, ask them these questions:

1. Does the model show the actual smell?
2. Does the model show how the odor got from the source to your nose?
3. Does the model explain how we smell things from a distance?

**Then switch roles**: Student 2 shares their drawing, and Student 1 asks the questions.
**Discuss together:**

1. What is similar about your drawings?
2. What is different?
3. How can you combine both of your drawings into one drawing that explains how we smell?

When you and your partner have shared with each other, go on to Step 3.

**(b)**

**Step 3: Draw with your partner**
Go to the **WeModel** module on the right side of your screen and open the file called **Lesson 1: Draw how we smell.**

**Student 1:** Create a session and wait for student 2 to join – be sure to tell your partner what the session number is! Click "OK" only after your partner has joined the session!
**Student 2:** Ask your partner which session number to join, and join that session.
**Collaborate:**
Now it's time to combine your drawings. Draw one picture to show what you both think happens: How does a smell get from the source of the smell to your nose?

Remember that you must talk to each other in order for your collaborative drawing to work. If one person is trying to draw and another is trying to erase, you might end up losing your picture!

When you are done with your drawing, go on to Step 4.

**Step 5: Explain your drawing**
Once you and your partner have a drawing that you both agree shows what the smell is and how it gets from the source to your nose, explain what you drew.

**Collaborate:**
Go to the **WeWrite** module on the right side of your screen and open the file called **Lesson 1: Explain your drawing.**

**Student 1:** Create a session in WeWrite and wait for student 2 to join – be sure to tell your partner what the session number is! Click "OK" only after your partner has joined the session!
**Student 2:** Ask your partner which session number to join, and join that session. You must also be in WeWrite.

Together, use your drawing to explain how the smell traveled from the source to your nose.

Remember that you must talk to each other in order for your collaborative writing to work. Only one person can type at a time! So discuss first what you will write, then choose one person to type the explanation.

When you are done explaining your drawing, flip your tablet so that the screen is **FACE DOWN** on the desk. Wait for your
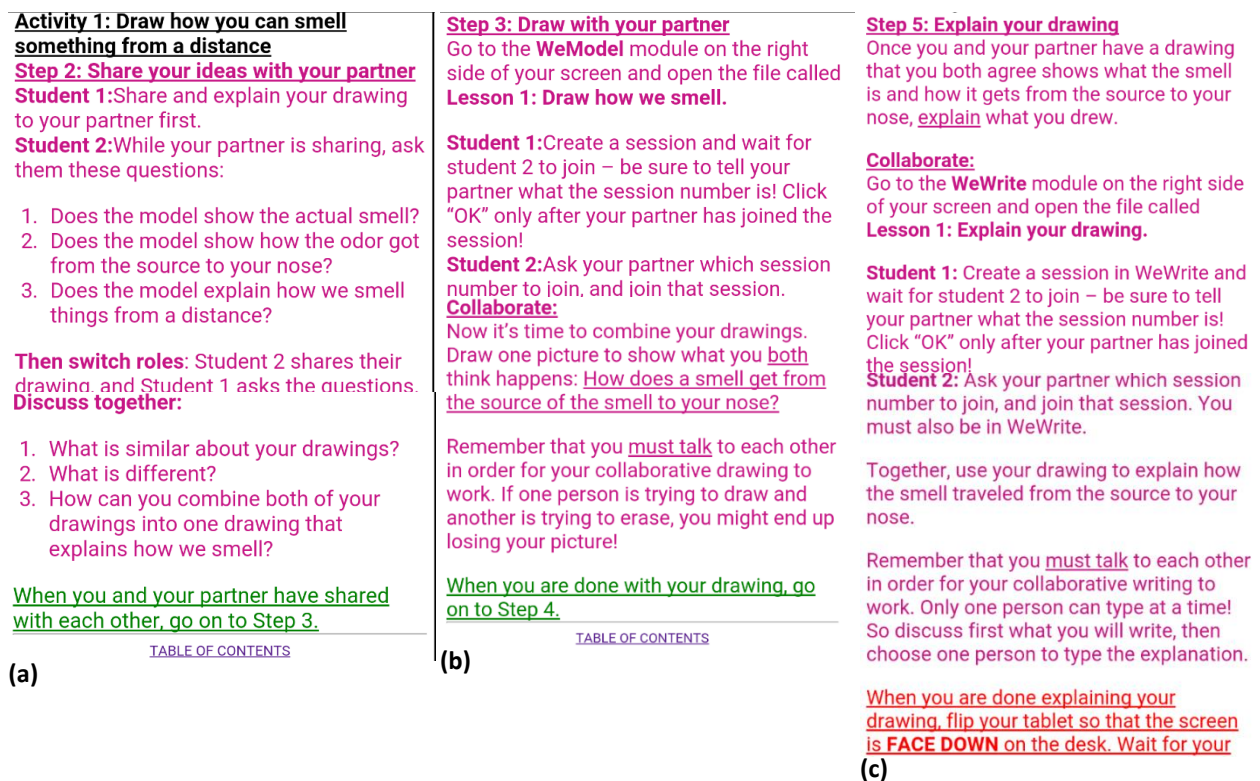
**(c)**

*Figure 4.1.* Screenshots from WeRead, Lesson 1, guiding students' (a) sharing of individual work, (b) collaborative work in WeModel and (b) collaborative work in WeWrite.

**4.2.2. Coordinative talk.** Coordination in this study was defined as talk that focused on the coordination, planning, and monitoring of the learning task (Gijlers et al., 2013). In each of the student cases studied, across all of the sampled lessons, the predominant type of talk in which the students engaged was coordinative talk, in which they discussed what would be put into their model or explanation, who would draw or write it, and where, as shown in Table 4.2, above.

Built into the design of *WeInvestigate* were prompts, such as the one in Figure 4.1, to assist students in planning and monitoring collaborative tasks (Quintana et al., 2004; Linn et al., 2004), and more specifically, for students to talk with each other about how they will draw their models or write their explanations (see Chapter 3, section 3.2.3.). In this example from Lesson 1, students were given individual "think time" (Stahl, 1994) in which they constructed their own model, then had time to talk to each other about that model (Figure 4.1a) and how they would then construct a joint model (Figure 4.1b). Such prompts and lesson structure may have inadvertently supported more coordination than collaboration around modeling tasks.

For instance, in the following example from Rose and Uma's case, coordinative talk dominated particularly Rose's talk during the model construction task in Lesson 1. Reflecting the designed prompts shown in Figure 4.1a, the girls made sure to coordinate the drawing of the source of the smell (U61-63, U69, etc.), the nose/person receiving the smell (U64-68, U71-78, etc.), and a representation of the smell (U75, U79, U81, U83). Accompanying this coordinative talk was primarily low-level transactive talk – a series of elicitations, externalizations, and quick consensus – all of which were focused on the appearance and aesthetics of the model. As in most instances in which the students were co-constructing models, Rose and Uma relied on coordination to complete the modeling task, as opposed to discussing the scientific content of the task. Gijlers and colleagues (2013) found a similar result in their experimental study of students'

use of scripts to collaborate around a drawing on a shared digital canvas. Specifically, they found that when students had to combine their separate drawings into one shared drawing – such as was the case in Lesson 1 - there was increased need for coordination of the task (Gijlers et al., 2013).

*Excerpt 4.1*

| | |
|---|---|
| 3-1-U61 | Rose: Oh, would you mind if it's the onion? |
| 3-1-U62 | Uma: No, that's fine. |
| 3-1-U63 | Rose: That's a bad onion. |
| 3-1-U64 | Uma: Should we just draw a big nose? |
| 3-1-U65 | Rose: Yeah, kinda like mine. |
| 3-1-U66 | Uma: Can I draw the nose? |
| 3-1-U67 | Rose: Yeah. |
| 3-1-U68 | Uma: I'm gonna draw the nose over here. |
| 3-1-U69 | Rose: Wait, don't do it until after, cuz it might erase it.  This is an ugly onion. |
| 3-1-U71 | Rose: Can I draw the person? |
| 3-1-U72 | Uma: Yeah.  I'll just draw a nose. |
| 3-1-U73 | Rose: I wanna draw him sitting.  It's easy. |
| 3-1-U74 | Uma: I'm gonna make these middle hands. Oh. |
| 3-1-U75 | Rose: Oh yeah, you can draw the hands.  Make it huge like a beak.  Oh wait, wait, I wanna draw the molecules. Dang it, what happened?  Oh, you did that? |
| 3-1-U76 | Uma: Yeah. Okay, that didn't work. |
| 3-1-U77 | Rose: Wait, wait, wait.  I have to draw the mouth here.  I drew that awesome. |
| 3-1-U78 | Uma: I'm gonna erase it. |
| 3-1-U79 | Rose: Can I just draw a bunch of circles all over?  I'm gonna do that over your lines. Oh yeah, I need to draw the mouth. |
| 3-1-U80 | Uma: Yeah, there's a really bad nose.  It's like a polka dotted face. |
| 3-1-U81 | Rose: How about circles equal molecules. |
| 3-1-U82 | Uma: What does that say?  What's that say? |
| 3-1-U83 | Rose: Circles equal molecules. |
| 3-1-U84 | Uma: No, what is—no, on the top, here. |
| 3-1-U85 | Rose: The scent. |

In addition to the students engaging in high amounts of coordinative talk overall, there was more coordinative talk during the model construction tasks than there was during the explanation writing tasks, as shown in Table 4.3.

Table 4.3.

*Percent of on-task coordinative talk for each group across all sampled lessons.*

|          | Group 1 | Group 2 | Group 3 |
|----------|---------|---------|---------|
| WeModel  | 42.36   | 50.94   | 42.04   |
| WeWrite  | 32.61   | 33.00   | 24.73   |

The observed differences in the amount of coordinative talk between WeModel and WeWrite may have been due to differences in the requirements of modeling and writing tasks, as well as the degree of collabrification of these modules, both of which were reflected in the design of the directions and prompts. For instance, to co-construct a model, students had to decide what to draw, where in the space to draw it, and how to draw it, including what it should look like. For the students in our study, some of this discussion and coordination of tasks occurred before any drawing began. However, once the students began drawing, the fluid nature of the collabrified space in WeModel meant that much more discussion and coordination was warranted during the modeling task. For example, in Excerpt 4.2, from Lesson 7, before Mary and Hannah began drawing, they coordinated who would draw what (i.e., boxes) in the model (U231-U233). Hannah then began to draw (U234), and because of the collabrified technology, Mary monitored and provided feedback related to the appearance of the boxes Hannah was drawing (U235-237).

*Excerpt 4.2*

| | |
|---|---|
| 1-7-U231 | Mary: You can do two, and I'll do two. |
| 1-7-U232 | Hannah: I'll do the first one and the last one. |
| 1-7-U233 | Mary: Okay. I'll do the middle. |
| 1-7-U234 | Hannah: Okay. Well, we have the four boxes. |
| 1-7-U235 | Mary: Make sure they fit. |

| 1-7-U236 | Mary: That's big. |
|---|---|
| 1-7-U237 | Mary: Hey. [Laughter] No. The last one is not a box. |
| 1-7-U238 | Hannah: It's not? |
| 1-7-U239 | Mary: No. Cuz you have to get— |
| 1-7-U240 | Hannah: I thought it was. Okay. Fine. |

In contrast, to co-construct an explanation less coordination was necessary. Students only

had to discuss what they wanted to say, and then decide who would type it, a point that was

reinforced by text in WeRead (see Figure 4.1c). Most often, because of the fact that only one

student could type at a time, this discussion necessarily occurred before any typing began. For

example, in Excerpt 4.3, also from Lesson 7, Mary and Hannah see that there is only one

"question" in WeWrite they need to answer. They first decide who will "do it," saying that they

will both identify the content of the answer and Mary will type it into WeWrite (U404-407).

Only after some discussion about what they should say (U408-421), do they begin to type

(U422).

*Excerpt 4.3*

| 1-7-U404 | Mary: How many questions? There's only one? Okay. |
|---|---|
| 1-7-U405 | Hannah: Well, that's easy. |
| 1-7-U406 | Mary: You wanna do it? |
| 1-7-U407 | Hannah: You write. We'll both come up with the answer, and you write it. |
| 1-7-U408 | Mary: That's easy. The liquid, it comes out with the liquid, and then the molecules become more spread out. Then when it turns into a gas. |
| 1-7-U409 | Hannah: First, it's almost like a liquid, because it has— |
| 1-7-U410 | Mary: It is a liquid. Oh, no! We have one above. It's not supposed to be like that. Whatever. |
| 1-7-U411 | Hannah: No, I was trying to draw the line and I messed up. I put it—yeah. |
| 1-7-U415 | Hannah: They slowly move above the line—line, the surface, and turn into a gas. |
| 1-7-U416 | Mary: Yeah, so the liquid molecules slowly— |
| 1-7-U417 | Hannah: No, I like mine. |
| 1-7-U418 | Mary: What? You said I was supposed to be— |
| 1-7-U419 | Hannah: I said it slowly turned into a gas because they go above the surface. Bam. What? |

| | |
|---|---|
| 1-7-U420 | Mary: They?  The molecules? |
| 1-7-U421 | Hannah: The molecules move above the surface and turn into a gas.  Bam.  What?  Okay, I'll write it. |
| 1-7-U422 | Mary: No, I wanna write it. |

Because collaborative tasks often involve many different parts, or activities, that need to be done, the need for coordination of the task arises (Erkens et al., 2005). Thus, coordination is an important and necessary part of the collaborative process (Roschelle & Teasley, 1995; Palincsar & Herrenkohl, 2002). The predominant talk in which the students in this study engaged was coordinative talk. Thus, the collabrified technology, and additional supports built into *WeInvestigate* worked to support students' coordination as they completed modeling tasks. However, some of the time that they spent coordinating, planning, and monitoring the tasks, was time that could have been spent collaboratively engaging with the scientific reasoning of the task. Given that we did not see nearly as much content or high-level transactive talk, this finding implies that the collabrified technology and additional supports did less to support these other kinds of talk.

Kuhn (2015) and others (e.g., Tomasello & Hamann, 2012; Henderson & Woodward, 2011; Crook, 1995, 1998) have noted that collaboration, similar to students' science content learning, follows a developmental trajectory, or a "learning progression." If we consider a theoretical collaboration "learning progression," in which coordination spans the progression but is the dominant mode of interaction on the "novice" end of the progression, most of the interactions of the students in this study could be characterized as "novice." A reliance on coordination to complete tasks, such as we saw from the students in this study, reinforces the fact that these students were novice collaborators, and generally remained so throughout the unit. This was not surprising, given that these students had very little, if any, prior experience collaborating with each other co-constructing artifacts in their science class.

**4.2.3. Content talk.** The overall amount of science content talk across all sampled

lessons was quite low, as shown in Table 4.2. My analysis also revealed that there was more

content talk present in WeWrite than WeModel tasks, as shown in Table 4.4. It may have been

that here, too, the prompts provided in WeModel and WeWrite, which were reflective of both the

differences in the collabrification of these modules, as well as the tasks themselves, may have

inadvertently contributed to this difference in the students' science content talk. Screenshots of

the prompts in WeRead for Lesson 7 to support the co-construction of a model of bromine

evaporation in WeModel and the subsequent explanation in WeWrite are shown in Figure 4.2.

Table 4.4.

*Percent of on-task content talk for each group across all sampled lessons.*

|          | Group 1 | Group 2 | Group 3 |
|----------|---------|---------|---------|
| WeModel  | 2.31    | 4.48    | 3.00    |
| WeWrite  | 10.47   | 13.74   | 12.37   |

**Collaborate:**
Use what you already know from the class consensus model! The following questions will help you think about how to draw a model of what you observed in the video:

1. **What state of matter does the bromine start out as?** Begin developing your model by drawing the class consensus model for this state of matter. You will be drawing a process so put this on the left-most side of the modeling space.
2. **What state of matter does the bromine turn into?** You know this is the final piece of the process, so draw the class consensus model for this state of matter on the far right side of the modeling space.
3. **What do you think must happen to the bromine molecules in order for them to get from the starting state (on the left) to the final state (on the right)?** Fill in the space in the middle with what you think happens to the molecules.

Open WeModel, Lesson 7: Initial bromine evaporation model.
**(a)**

**Explain:**
When you and your partner have completed your model for the bromine molecules, go to **WeWrite** and open the file **Lesson 7: Initial evaporation model explanation**. (student 1 creates session, student 2 joins).

**Talk with your partner** and decide how you can best explain your model, then choose one person to type in your explanation. Explain what happens to the bromine molecules in your model. ☐

Be prepared to share your model and explanation with your class.
**(b)**

*Figure 4.2.* Screenshots from WeRead, Lesson 7. Prompts to support co-construction of a (a)

model of bromine evaporation, and (b) an explanation for students' bromine evaporation model.

To successfully use the guidance of the WeModel prompts (Figure 4.2a) to construct a model, students had to demonstrate their ability to identify relevant components of the consensus models (i.e., the initial and final states), and then hypothesize what the transition between them would look like at the molecular level.  The emphasis in the WeRead support was placed on how to complete the drawing task (e.g., "put this on the left-most side of the modeling space"), including what components should be in the model (i.e., initial state of matter, final state of matter, something to show the transition between them). This support for students' talk and modeling was quite structured, and guided by low-inference, identification-type questions, which may have obviated the need for students to engage in science thinking beyond completing the task according to these prompts, an emphasis that was reinforced by the teacher during implementation[17].

The prompts for the use of WeWrite (Figure 4.2b), on the other hand, were more open-ended, less structured in terms of what should be present, and more focused on the science content that could explain processes shown in the model. Because students were explicitly prompted to "explain," science content talk was more present in their discourse during WeWrite tasks than WeModel tasks, as shown in Table 4.4.

The observed differences in the content talk between WeModel and WeWrite tasks may also have been due to differences in the nature of drawing and writing tasks. Though science content knowledge was still required when drawing their models, mentioned previously, we observed that the knowledge students shared was generally more implicit in the contributions

---

[17] In Lesson 7, the teacher provided students with an additional support in the form of four boxes that students were meant to fill in with each of the required model components from the question prompts. While this did successfully support students' model construction, it may have also contributed to a more formulaic approach in which students did not have to engage as much in thinking about the process they were modeling.

they made. In Excerpt 4.4, from Lesson 7, we see an example of the implicit nature of students'

content talk as Mary and Hannah engaged in co-constructing their evaporation model. The

discourse in this excerpt is a continuation of the discourse shown in Excerpt 4.2. After the

discourse shown in Excerpt 4.2, in which they talked a little to decide who would draw what, the

girls split up the task of drawing, with each girl drawing a different part of the model. Because

they had not talked enough prior to drawing (Excerpt 4.2) about what they would draw in their

model, and how they would draw it, once they began the task (Excerpt 4.4), they realized they

needed to talk more, illustrating the more fluid nature of talk and model construction in

WeModel, mentioned previously.

   As Hannah drew, she externalized some explicit content-based reasoning for how she

was about to approach drawing her part of the model (U297). She was interrupted by Mary, who

was preoccupied with the portion of the model she was responsible for drawing, as she elicited

Hannah's opinion (U298). This elicitation began an interaction (U298-U305) between the girls

about the placement of a "liquid line" in the "container" in Mary's piece of the model so that it

made sense when combined with Hannah's piece of the model. There was some science

knowledge implicit in their exchange, but much was left unsaid, and presumed about what they

both knew about evaporation in order to successfully construct the model, shown in Figure 4.3.

*Excerpt 4.4*

| | |
|---|---|
| 1-7-U297 | Hannah: Gas fills its container, so I don't have to like— |
| 1-7-U298 | Mary: Well, should the line go away on the second one cuz it's evaporating, or should some go outside the line and then the line goes with the second one? |
| 1-7-U299 | Hannah: What are you talking about? |
| 1-7-U300 | Mary: You see the line that's liquid. Then, should the line still be there? Then, I'll make some up above the line cuz the liquid was still there. |
| 1-7-U301 | Hannah: Yeah. Yeah. |
| 1-7-U302 | Mary: Okay. Then, the line just goes like—but it's not filled up yet, or just keep the line. |
| 1-7-U303 | Hannah: Well—- like this. |

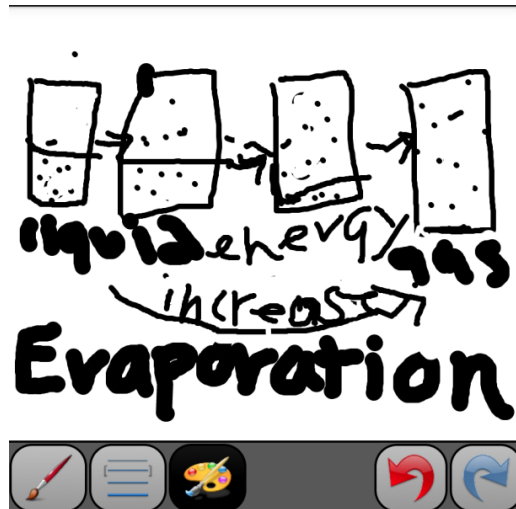| 1-7-U304 | Mary: No. Then, just fill the container. |
| 1-7-U305 | Hannah: Yeah.  No.  Not fill it up like—then, it goes to my picture.  No.  Wait.  You gotta erase some of that. […] |



*Figure 4.3.* Mary and Hannah's bromine evaporation model.

Although it was rare, when students did engage in explicit science content talk during model construction tasks, they did so spontaneously;  that is, not in response to any of the more explicit supports built into the design of *WeInvestigate*. In general, more explicit science content talk arose during model construction tasks when a student felt the need to explain a suggested contribution to a model. An example of this can be seen in Excerpt 4.5, from Rose and Uma's case in Lesson 7. Uma began by suggesting they needed to figure out how they would draw some part of their model (U192), when Rose interrupted to suggest a contribution (U193). Uma did not agree with Rose's suggestion, so proposed an alternative contribution (U194). As she did so, she began to draw in her contribution, allowing Rose to see her thinking about how to draw the molecules ("the little") (U195). Rose did not disagree or stop Uma, so Uma continued drawing and externalized another contribution to the model (U196). Also in this utterance, Uma took up some coordination of the task, breaking up the task so they both could draw different parts at the same time (U196). However, rather than taking up Uma's suggestion that Rose draw the gas

stage of their model, she monitored Uma's drawing and suggested a new contribution, that she

draw a "wave" (U197). Uma did not acknowledge Rose's suggestion (U198), so Rose persisted

(U199). At Uma's request for clarification (U200), Rose provided some initial reasoning for her

suggestion (U201). She later provided more reasoning (U210) to support the inclusion of her

suggested contribution of a wave.

*Excerpt 4.5*

| | |
|---|---|
| 3-7-U192 | Uma: All right, so now we gotta figure out how we're gonna make— |
| 3-7-U193 | Rose: Wait first we're gonna draw the bowl. |
| 3-7-U194 | Uma: No, we gotta draw the molecules. |
| 3-7-U195 | Rose: Oh, so can we just draw like little—oh. |
| 3-7-U196 | Uma: First we gotta draw it as a liquid. How 'bout one of us draws the gas up here and the liquid up here. All right, so I'll draw the liquid up here. |
| 3-7-U197 | Rose: Draw like the wave. |
| 3-7-U198 | Uma: Oh, yeah. No circles. I can't remember that. Now they go like that and that and that. |
| 3-7-U199 | Rose: Wait, draw the wave. |
| 3-7-U200 | Uma: What? |
| 3-7-U201 | Rose: It's a wave so you know it's water. |
| 3-7-U202 | Uma: I don't know. |
| 3-7-U203 | Uma: Well, it's not water. |
| 3-7-U204 | Rose: A liquid. |
| 3-7-U205 | Uma: It's Bromine. |
| 3-7-U206 | Rose: It's liquid. |
| 3-7-U207 | Uma: It's supposed to be the Bromine. |
| 3-7-U208 | Rose: Yeah, but Bromine is liquid, Bromine is liquid. |
| 3-7-U209 | Uma: All right, so let's draw it. And draw our…wave. |
| 3-7-U210 | Rose: Because liquid doesn't fill the container. |
| 3-7-U211 | Uma: Like that? |
| 3-7-U212 | Rose: Yeah, liquid doesn't fill the container. Wait, that looks like the box. Thanks, Uma. That was such a perfect wave. |

Students' generally implicit content-based model contributions were in contrast to the

suggestions students made as they constructed their explanations, which were more explicit

content-based statements of what the model was meant to show. Although Mary and Hannah's

explanation of their bromine evaporation model, shown previously in Excerpt 4.3, was really

more of a description of their model than an explanation of what they thought happened to

bromine as it evaporates, it illustrates the more explicit nature of the content talk that occurred

more often during explanation tasks in WeWrite. Namely, the process of evaporation "comes out

with the liquid" (U408), and the "molecules become more spread out" (U408), and they "slowly move above the surface and turn into a gas" (U415, U419).

These findings have several implications for future iterations of *WeInvestigate*, and for the design of similar technology-based learning environments. I found that the directions and prompts designed for use with model construction tasks in particular, which were written to support students' talk around effectively completing the modeling task, seemed instead to support students' more coordinative, less content-based, and more task completion-focused talk. I also found that students' science content knowledge shared during model construction tasks was implicit in their suggested contributions to the model. When students made explicit science content remarks it was most often when there were conflicting ideas, seen as an essential component of collaborative discourse, and one that propels it forward (Kuhn, 2015; Schwarz et al., 2000), and when a student felt the need to provide reasoning to support a suggested contribution, as we saw in Excerpt 4.5. In order to encourage more negotiation and consensus-building talk during model construction tasks, I recommend designers pay close attention to the language of the directions and prompts to ensure less of a focus on task completion (which would likely lead to a reliance on coordinative talk, as we observed), and more focus on getting students to articulate more about their science thinking, about the science of the components of the model, for example, and why those representations do or do not make sense relative to the phenomenon being modeled. Instead of including prompts checking only that students included specific components in a model (e.g., Figure 4.1a), prompts can check that students are understanding the science reasoning behind the inclusion of those components. Reminders in the form of pop-up windows that include prompts to explain each suggested contribution to a model may better support students in making their knowledge more explicit (e.g., Linn et al., 2004)

during model construction tasks. Training for students, via the teacher, or the use of interactive scripts (e.g., Fischer et al., 2013, Noroozi, et al., 2012), may also help students learn to elicit each other's ideas, and manage both conflicting ideas and agreement.

**4.2.4. Transactive talk.** Instances in which students were engaged in primarily coordinative talk (e.g., Excerpt 4.1 above), generally contained very little, if any, explicit science content talk. These findings are consistent with students' discourse that also primarily consisted of low-level transactive talk. High-level transactive talk, in which students engaged in consensus-building around ideas, considered necessary for students' productive collaboration (e.g., Teasley, 1997), was even more rarely observed across all sampled lessons than was the content talk, as shown in Table 4.2. Also, we generally saw slightly more high-level transactive talk as students engaged in WeWrite to construct explanations than we saw when students constructed models in WeModel, shown in Table 4.5. The nature of the prompts in WeRead, which, again, were reflective of the collabrification capability and of the nature of the tasks, and which may have inadvertently contributed to the higher amounts of coordinative talk, may also have had a similar effect in contributing to lower amounts of high-level transactive talk as students engaged in these modules in different ways.

Table 4.5.

*Percent of on-task high-level transactive talk for each group across all sampled lessons.*

|  | **Group 1** | **Group 2** | **Group 3** |
|---|---|---|---|
| WeModel | 1.39 | 4.72 | 3.60 |
| WeWrite | 3.36 | 7.71 | 1.61 |

Generally, instances in which students were engaged in more explicit content talk, such as when a student felt the need to explain a suggested contribution to a model, as shown in Excerpt 4.5 above, overlapped with instances in which more high-level transactive talk occurred, suggesting a possible relationship between these two kinds of talk. In Excerpt 4.5, Uma's

disagreement (U202) about Rose's suggestion to include a "wave" (U201) precipitated a consensus-building discussion between the girls that would not have occurred (there would have been no need for it) if Uma had simply agreed and added Rose's suggestion into the model. Uma elaborated on why she disagreed with Rose's suggestion (U203). Rose implicitly conceded that Uma was right; it was not water that they were modeling, but a "liquid," so she clarified her previous comment (U204). Uma clarified even further, still not persuaded by Rose's suggestion (U205). Rose held her ground about what they were modeling (U206). Uma pushed back on Rose, reminding her that they were specifically modeling bromine (U207). Rose similarly pushed back on Uma, not necessarily in disagreement, but clarifying that they actually were both in agreement (U208). At this point, even though Uma agreed to take up Rose's idea to draw a wave (U209), Rose added more reasoning to support her idea, using a science concept they had learned to further support the need for a "wave" in their model (U210). To conclude the negotiation around this single contribution, Uma checked with Rose that she had drawn the wave correctly (U211). Rose approved, adding more reasoning to support her idea (U212). Thus did Uma and Rose engage directly with each other's ideas, the result of which was an uptake of Rose's idea, by Uma, for inclusion in their model.

Another reason we may have seen more high-level transactive talk during WeWrite tasks was due to differences in the design of the technology (and thus the ease of use) of the WeModel and WeWrite modules. Because of how students had to first click in the appropriate place, then type, and then enter text, editing the text, once some text was written and entered, was not as easy as with drawings in WeModel. Also, once text was entered, it was unfortunately too easy for that text to be lost when a student tried to add more text to the response. This led to some frustration amongst students, and perhaps even truncated responses. Because WeWrite was not

easily editable, students may not have engaged in as much negotiation as may have been possible if it had been as easy to use as WeModel. Instead, there may have been a tendency to come to consensus and "get it right" the first time.

Because we generally observed some overlap in excerpts when students engaged in high-level transactive talk and when they made explicit content-based statements, our suggestions for future iterations of *WeInvestigate*, and similar technologies, are consistent, especially around the need for prompts that encourage students to make their own science ideas more explicit (Linn et al., 2004), and which supports students to confront and negotiate regarding their partner's ideas. High-level transactive talk and consensus-building discourse amongst students are generally not the norm in terms of the language demonstrated in schools (Blumenfeld et al., 1996). It is a skill students must learn, and a challenge for teachers to manage and support (Kuhn, 2015). More explicit scaffolds to support students' collaborative discourse from the beginning of the unit are needed. For example, detailed interactive "scripts" (e.g., Fischer et al., 2013; Noroozi et al., 2012), or adaptive, "intelligent tutors" (e.g., Diziol et al., 2010) can model and teach students how to engage with one another to discuss their ideas. As the unit proceeds, the heavily scaffolded scripts or "tutoring," could be reduced to "collaboration reminders" in the form of pop-ups with sentence starters, or removed altogether as the language and behaviors of this kind of talk become internalized by students.

In this iteration of *WeInvestigate*, students generally constructed models together, but there were lessons (e.g., Lesson 1 and 12) in which students were first given individual think time to draw and explain their own model before sharing with a partner and co-constructing a model. Allowing students individual think time (Stahl, 1994) is a widely used technique to support students in making their thinking visible to themselves (Linn et al., 2004), and then later

to others, such as in a "think-pair-share" (Lyman, 1987). We utilized this strategy (see Chapter 3, section 3.2.3.) in the hopes that as students shared their individual models, they would engage in negotiation, and have to persuade each other, and come to consensus about the content and appearance as they co-constructed a model. Our findings showed, however, that providing students with individual think time may have resulted in the production of less collaborative artifacts. That is, during Lesson 1, for example, in both the case of Rose and Uma, and Mary and Hannah, their final jointly-created models were more attributable to one member of the pair (e.g. Schwartz, 1995). This finding is similar to Looi and Chen (2010), who made a similar observation in their study of elementary students' use of a collaborative workspace called Group Scribbles. Specifically, they noted that each student relied on his or her own individual work in group discussion, and they even saw a student recreate his individual solution in the collaborative workspace, rather than engage collaboratively with the ideas of other members of the group. We believe that when the students in our study shared their individual models and explanations, they had a tendency to focus on the similarities between them, and thus missed out on key differences that, had they been confronted and negotiated, may have resulted in further science knowledge building. The focus on similarities also meant more coordinative talk, as there was no apparent reason for them to engage in consensus building talk – they had already reached consensus!

Although our findings suggest, consistent with Looi and Chen (2010), that as a result of think time, the students became attached to their individual ideas, such that when brought into a collaborative endeavor they were unwilling (or did not see the point) to engage meaningfully with their partner's ideas, we are still committed to using think time as a strategy to make students' individual thinking visible and prepare them to engage collaboratively with a partner.

To account for this tendency of students to hone in on similar ideas with a partner, we suggest a strong need to develop prompts, scripts, or other such supports for students to confront and manage conflicting ideas. Our prompts, which told students to "share ideas," and "talk" and "collaborate" did not help them identify when their ideas were truly the same versus when they were different, nor did they help students resolve differences in their ideas. Instead, supporting students in "persuading" and "arguing" regarding their content-based contributions may better support students engaging in more high-level and content-based talk around the more authentic and meaningful creation of models and model-based explanations (Asterhan & Schwarz, 2007; Garcia-Mila et al., 2013).

    **4.2.5. Artifact mediation.** In general, the collabrified nature of WeModel seemed to support students' joint attention to a shared representation through the co-construction of models. The power of the collabrification seemed to arise from the students' ability to immediately see what a partner was drawing and easily and immediately respond to it verbally, or add to or modify it as necessary through the drawing. In this way, WeModel supported pairs of students' discourse, both mediated by the model, and through the model itself in that a drawn contribution to the model, just like a verbalized contribution, could be seen as an externalization, open to agreement, critique, and modification. For example, in Excerpt 4.5, as Uma drew (U192-U196), the collabrification of WeModel allowed Rose to monitor the drawing, and make a suggestion (U197), which began a negotiation between Rose and Uma, detailed in the previous section. Thus, the model mediated their talk. Similarly, as a result of their negotiation, they came to consensus and Rose's suggestion was included in the model (U209-U212). In Excerpt 4.4, the collabrification of WeModel allowed for part of Mary and Hannah's discourse to occur *through* the model, thus mediating model construction in a slightly different way. For instance, as Mary

interrupted Hannah to elicit her opinion, she illustrated her question through the model, referring to aspects of the model only someone also looking at the model would understand: "the line," "some," and "the second one." Mary continued to simultaneously draw and make inquiries of Hannah (U302), to which Hannah responded also through the model with a drawn externalization of her own (U303). In this excerpt, not all of the girls' contributions were verbalized in such a way that we knew what they were; in this manner, the discourse that occurred partly through the model itself mediated model construction and vice-versa.

In both of these examples we find evidence of ways in which the models were able to mediate students' science talk and thinking, either through explicit verbalizations, or through the model itself. However, consistent with the generally low amount of content talk during model construction tasks, this type of mediation was rare. More often, student talk mediated (and vice-versa) the inclusion of aesthetic features of the model. For example, in Excerpt 4.6, from Lesson 12, Mary and Hannah engaged with the modeling task in such a way that the model mediated their talk, specifically as it pertained to some aesthetic aspects of their model. Hannah began drawing a nose, and narrated as she did so – a drawn externalization of her idea (U36). Again, the collabrification of WeModel allowed Mary to immediately see and monitor Hannah's drawing, to which she provided critique on its appearance, even taking it upon herself to make changes to what Hannah had drawn (U37). Hannah, in turn, did not agree, or did not accept Mary's changes (U38), and decided to make changes now to Mary's drawing, also focused on the appearance of the object, the person (U40, U42). Mary conceded to Hannah's changes and took charge of making color changes to the onion she had drawn (U43). Thus did the model mediate their talk (and vice-versa), as some of their discourse occurred *through* the model, through the sharing of, and modifications to, drawn ideas. In this case, however, the students

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were focused on the inclusion of aesthetic features of their model (e.g., what the person and the onion looked like), rather than on the meaning of these representations, and their purpose in the model.

*Excerpt 4.6*

| | |
|---|---|
| 1-12-U36 | Hannah: Then I'll draw the nose over here, there's your little nostril. [Laughter] |
| 1-12-U37 | Mary: Looks like something from Ratatouille. It looks crazy. [Laughter] Put it away. I kinda like it. Just draw a person. Stop it, just draw a person. No, draw a person. There. |
| 1-12-U38 | Hannah: Hey, stop that. |
| 1-12-U39 | Mary: No, the person is good, the person is good, the person is good. |
| 1-12-U40 | Hannah: I gotta make it better, I'm sorry. |
| 1-12-U41 | Mary: You don't like my stick person? |
| 1-12-U42 | Hannah: I have to make it better. |
| 1-12-U43 | Mary: Okay, fine, I'll fix my onion. I'll color my onion. What color are onions? Are onions white or are they gray? |

As illustrated in the examples provided, in WeModel the shared representation of the model was able to mediate student talk (and vice-versa), and even when students were not always verbalizing as they drew, some of the discourse, and negotiation, between students, happened through the drawing itself as students would modify each other's drawn externalizations. This same flexibility for real-time interaction through the co-constructed artifact was not present in WeWrite, due to the delayed synchronicity of the module. However, students adapted how they interacted with each other and WeWrite to account for the delayed synchronicity, and so we saw a different way in which students' written explanations were able to mediate their talk. Specifically, students had to rely more on verbalization, and we often saw the typing student speak aloud before or during typing, as in the example shown in Excerpt 4.7. Rose typed, and read aloud what she was typing (U303). Because Uma would not have been able to read for herself what Rose was typing until Rose had entered the text, this had the effect, similar to WeModel, of allowing Uma the opportunity to provide immediate feedback on what

Rose was typing. As Rose stated what she was typing (or would type) (U303), Uma interrupted to disagree and correct her idea (U304).  Rose expressed confusion and requested clarification from Uma (U305, U309, U311). Uma tried to clarify and correct Rose's erroneous statement that they had seen water poured into the bromine in the video (U306, U308, U310, U312). As a result of this consensus-building conversation, Rose revised her contribution (U313), to which Uma added an additional thought (U314).  This way of engaging with each other and WeWrite seemed, in this instance, to support the potential for Rose's knowledge building. Because Rose spoke aloud what she was going to type into WeWrite, Uma was able to directly confront her suggested contribution, the result of which was a discussion, after which Rose revised her idea.

*Excerpt 4.7*

| | |
|---|---|
| 3-7-U303 | Rose: Okay.  The bromine started as a liquid.  Then when we poured water into it, the molecules started to— |
| 3-7-U304 | Uma: No, the bromine started as a liquid.  You don't pour water into it. |
| 3-7-U305 | Rose: What? |
| 3-7-U306 | Uma: You said the [clears throat]—sorry.  You said bromine started as a liquid and that you poured water into it. |
| 3-7-U307 | Rose: That's what I said. |
| 3-7-U308 | Uma: Yeah.  They didn't pour water into it. |
| 3-7-U309 | Rose: What? |
| 3-7-U310 | Uma: We didn't pour water into the bromine. |
| 3-7-U311 | Rose: They didn't? |
| 3-7-U312 | Uma: We're explaining the model [clears throat].  We're explaining the model, not [clears throat] what happened. |
| 3-7-U313 | Rose: Oh, so just say bromine started as a liquid and then the molecules started to spread apart. |
| 3-7-U314 | Uma: As they evaporated. |

Thus, while we did see students interact verbally as one student typed, and we saw students take turns typing and providing feedback on their partner's work, we did not observe the same capability of WeWrite to support interaction through the written artifact as we did with WeModel. Therefore, we suggest changing the functionality of WeWrite so that it is more

immediately synchronous like WeModel. In addition, we observed a greater tendency for students to be off-task during WeWrite tasks, likely because of its capacity to allow one student to type at a time, leaving the other student with seemingly nothing to do.

Given the push to have students engage in authentic and meaningful science practices (NGSS Lead States, 2013; NRC, 2012), reflected also in our theoretical stance, we would like to see students talking more science as they are coordinating the construction of models, something rarely observed in our data. The focus by students on the aesthetic features, or appearance, of the models is a well-documented phenomenon (e.g., Schwarz et al., 2009). However, the design and language of the prompts in *WeInvestigate* may have further contributed to this focus on aesthetic features in that for some models students were prompted to "check" that certain components were present, as described previously (see Figure 4.1a, Figure 4.2a). Additionally, given the technological limitations of WeModel at the time of our study, there was no way for WeModel to support prompts *during* modeling that may have encouraged students to think more about what components should be included in the model, why they should be included, and what their representational meaning was. As the functionality of tools like WeModel evolve, they should better be able to support prompts to "explain" model contributions during modeling tasks, and hopefully steer students away from a focus on aesthetics.

## 4.3. Making connections across modules

As described in Chapter 3 (section 3.2), *WeInvestigate* was designed with a split screen which allowed for two modules to be opened simultaneously in the app. This was purposefully done to support students' use of different modules in the service of each other. Because our technology could not support additional features, such as pop-ups, in the other modules, WeRead contained all the information necessary for students' use of the app. As such, it was expected that

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WeRead would most often be one of the modules always open on one side of the *WeInvestigate* screen, and reminders of this were even written into the text. For example, in Figure 4.1, the WeRead text explicitly tells students to open WeModel (4.1b) or WeWrite (4.1c) on the right side of the screen. During implementation it was observed that students followed these instructions, and, more often than not, WeRead was always open on the left side of students' tablets, while one of the other modules was open on the right. This is opposed to, for instance, having WeModel and WeWrite open simultaneously, which was rarely observed.

A related finding is that analysis showed that students were generally not making spontaneous or explicit connections between the model and phenomenon and/or the model and science concepts as they engaged in modeling tasks. Table 4.6 below shows the percentage of the total on-task talk of each group's model, content, and phenomenon talk across all sampled lessons, for model construction tasks. Model talk corresponded to utterances when students were discussing various aspects of a model, either ones they themselves were constructing, or a computer simulation. Content talk corresponded to utterances in which students were explicitly discussing science content, including times when they were reading the curriculum text. Phenomenon talk corresponded to utterances in which students made mention of the phenomenon being modeled. [See Appendix 2.A for more detail on these talk codes.] There was almost twice as much (if not more) model talk as there was content talk, and even less phenomenon talk for each group. The low co-occurrences of model and content talk, and model and phenomenon talk, that is, utterances which were both about the model and included explicit science content or mention of the phenomenon, reinforce the assertion that, during model construction tasks, students were not making explicit model-content or model-phenomenon connections.

Table 4.6.

*Percent of students' model, content, phenomenon utterances and co-occurrences*

|  | Group 1 | Group 2 | Group 3 |
|---|---|---|---|
| Model talk | 21.2 | 26.0 | 23.3 |
| Content talk | 12.2 | 14.3 | 8.0 |
| Phenomenon talk | 4.4 | 3.0 | 4.9 |
| Model x content | 1.4 | 2.3 | 1.6 |
| Model x phenomenon | 0.3 | 0.1 | 0.2 |

Although there were prompts in WeWrite that explicitly asked students to make connections between their explanation and their model, there may not have been enough guidance in *WeInvestigate* to support students' synthesizing and making connections between science concepts and models of phenomena across *WeInvestigate* modules. For instance, Figure 4.1b told students to open WeWrite on the right side, then it told them also to "Use your drawing to explain," but it did not include further guidance on how they should do that, given that they would have had WeRead already open one the left side. This finding is problematic given the goals of NGSS (NGSS Lead States, 2013) and the Framework (NRC, 2012) to have students engage in authentic science practices, which includes making model-concept and model-phenomenon connections (Rivet & Kastens, 2012).

Discussed previously, the extent of the guidance provided during model construction tasks was more related to helping students actually construct the model, rather than on making connections between the model and the phenomenon, or the model and science concepts. Guidance for making these kinds of connections was generally provided after students had the opportunity to construct their model, and was usually in the form of question prompts, which students responded to in WeWrite. Student talk during the modeling tasks, therefore, was more often focused on completing the task (i.e., finishing the model efficiently) rather than on thinking about what should be added to the model and why, scientifically, it needed to be added. However,

the few spontaneous moments in which students did make connections between their model and content, or their model and the phenomenon they were modeling, illustrate the possibilities for such talk. In the first example, from Lesson 7, shown in Excerpt 4.8, Hannah was in the process of contributing to her and Mary's model of bromine evaporation (U286), while Mary monitored on her own tablet, making suggestions and providing feedback (U287). In making a suggestion, Mary spontaneously (i.e., without prompting from the teacher or the app) provided some reasoning to support her suggested contribution. This reasoning was grounded in her knowledge about liquids, and representing liquids (U287), which Hannah subsequently took up and included in their model (U288).

*Excerpt 4.8*

| | |
|---|---|
| 1-7-U286 | Hannah: I do the outside boxes. |
| 1-7-U287 | Mary: Yep. Draw the line. No. No, no, no. It's liquid. You have to draw the line cuz it's a liquid. It sits in a puddle. |
| 1-7-U288 | Hannah: Oh, okay. I didn't know it was in that. |

In another example, also from Lesson 7, Rose and Uma had nearly completed their bromine evaporation model when Uma made the following connection between their model and the phenomenon, "We just drew it. All right, I'm gonna make the water brown because bromine is brown" (3-7-U472). This suggestion arose after much debate, and a little confusion, between the girls about what color to make the liquid in their model (they had wanted to make it blue, like water).

In a third example, as Hannah observed the temperature versus particle motion simulation in Lesson 6 (see Chapter 3, section 3.4) she not only made a connection between the model and the phenomenon, "Smell has a rough time getting to your nose" (1-6-U176), she also made a connection between what she was observing in the model and her own life experience, "I'm

amazed when I look at this and then you walk into the kitchen automatically you smell your

dinner or something that's cooking" (1-6-U206).

Though these moments were few and far between, they were particularly meaningful for

the ways in which students were able to make connections between their model and a science

concept, as in the first example, or between their model and the phenomenon they were modeling,

as in the second example, or even between the model and their life experiences, as in the third

example. To better support current reform efforts that include developing and using explanatory

models, it is hypothesized that students could make more connections among science content,

models they co-construct, and the real-world phenomena about which they are learning through

more simultaneous use of multiple modules, thus integrating their knowledge across the various

app features (Linn et al., 2004). This could be done through hyperlinks, or some other means of

connecting the modules to one another to make navigation between "pages" in WeRead and

other modules more streamlined.  Additionally, it may be helpful to "off-load" the important

guidance and supports found in WeRead to the other modules, such as through pop-up windows.

This way, other modules, such as WeModel and WeWrite, may be opened together for

simultaneous use.  For example, students may be better supported in thinking about the science

concepts demonstrated in their models if they were prompted to explain, through the use of pop-

ups, parts of their model as they drew (for an example, see Gijlers et al., 2013).

## 4.4.  Independence

The supports and guidance provided in WeRead, as well as the ease-of-use of the app,

seemed to be key features in supporting students' more independent use of the app to

collaboratively complete learning tasks. Described previously, WeRead was intended to guide

students through the use of the app, navigating between modules, providing directions and

guidance for the completion of tasks throughout the unit, and providing students with additional content knowledge via question prompts and scientific texts. Though there were marked locations where students were told to put their tablet down and wait for instruction from their teacher, they could easily proceed from one task to the next, should the teacher not want to stop and use those moments for whole class discussion. Toward the beginning of the unit, the teacher, consistent with her self-reported teaching style, attempted to maintain control of students' progression through the unit by choosing to stop at those moments identified in WeRead. She provided additional instruction for students, and guided them through reading the science texts as a whole class. As the unit progressed, she relinquished control more often, allowing some of the student pairs, including the focal pairs of students in this study, to progress through lesson tasks at their own pace.

Thus, the supports and guidance in the *WeInvestigate* learning environment enabled the teacher to allow her students a degree of freedom to progress through lessons at their own pace. She may not have allowed this, nor would the students have successfully been able to do this, if the necessary support had not been present. However, this independence also meant that there was a great deal of variation in how each group interpreted the text, and thus how they completed the task, and achieved accuracy in their final collaborative artifacts. For example, at the beginning of Lesson 6, students were asked to make predictions independently about the simulation they would be observing. They then used a sharing protocol found in WeRead, meant to provide some structure for their sharing and discussing their predictions with their partners. The sharing protocol from WeRead is shown in Figure 4.4 below.

**Student 1**: Share your predictions with your partner first.
**Student 2**: While your partner is sharing, listen and see if you agree.
**Switch**: When student 1 is done sharing, student 2 shares, and student 1 listens.

**Discuss together:**
1. Did you both make the same predictions?
2. How were your predictions different?
3. Were there any times when you both agreed that the motion of molecules would change, but did not agree on how they would change?

*Figure 4.4.* Screenshot from WeRead, Lesson 6, protocol for sharing predictions, and question prompts for discussion.

Mary and Hannah had conflicting predictions, which one might think would prime them for further inquiry and discussion about why their partner's prediction was different from their own (e.g., Kuhn, 2015; Schwarz et al., 2000). However, Mary and Hannah followed the guidance of the sharing protocol quite literally as it was presented in WeRead, without further discussion, shown in Excerpt 4.9. In their "interpretation" of the sharing protocol, Mary, "Student 1," shared each of her predictions (U9, U11, U13, U15), while Hannah, "Student 2," listened, and interjected her disagreement (U10, U12, U14, U16). The sharing protocol did not explicitly tell the students to elaborate on their ideas if they agree or disagreed, thus, despite having quite different ideas from her own, Hannah did not take the opportunity to elaborate on why she did not agree with Mary, or ask Mary questions to probe her thinking more.

*Excerpt 4.9*

| 1-6-U9 | Mary: Found it. Okay. Number one, I said I think the molecules will become faster. |
|---|---|
| 1-6-U10 | Hannah: I don't agree. |
| 1-6-U11 | Mary: I'm heartbroken. I'm gonna cry now. Now I gotta read number two. I said I think molecules—wait, what? I think it happens because when it's warmer the molecules speed up. |
| 1-6-U12 | Hannah: I don't agree. |
| 1-6-U13 | Mary: [Laughs] Number three, I think the molecules will become slower. |
| 1-6-U14 | Hannah: I don't agree. |
| 1-6-U15 | Mary: [Laughs] And number four, I think it happens cuz when it's cooler, the molecules slow down. |
| 1-6-U16 | Hannah: I don't agree. |

Rose and Uma's "interpretation" of the sharing protocol in WeRead was quite different from Mary and Hannah's. In Excerpt 4.10, Rose began sharing her predictions. She shared her first prediction and was going to immediately share her second prediction (U5), when Uma interrupted her. But rather than interrupt her to respond directly in some way to her prediction or explanation at this point, she interrupted her to suggest that they take turns sharing their predictions (U6). Rose agreed to this (U7).

*Excerpt 4.10*

| | |
|---|---|
| 3-6-U5 | Rose : I'll just go. If you added heat energy—if you added heated energy to a material, what would you expect would happen to the molecules? I said I would expect the molecules to get faster. It said, why do you think this? I said, I think of a teapot, and if you had regular water and it started boiling, you would see the bubbles and the molecules going faster, and then— |
| 3-6-U6 | Uma: Maybe we should both—maybe since you just did those two, I should do my two like that so we can compare those two first, cuz then we might think about these two and we're supposed to think about those two. That didn't make any sense. |
| 3-6-U7 | Rose : Read it. I know what you're she's saying. |
| 3-6-U8 | Uma: I said for number one that solids, liquids, and gas would all go faster. The molecules would all go faster. I said I thought that happened is because they would all gain the heat energy and go faster, like when liquid evaporates and turns into gas, which is faster. |
| 3-6-U9 | Rose : That's what I was thinking of, that it would boil and go into the air. |
| 3-6-U10 | Uma: I was thinking of the water cycle. |
| 3-6-U11 | Rose : Yeah. That's what I was gonna say. I forgot what I was gonna say, so I just changed it to a teapot. When the water it boiling, it also heats up and then goes away. Then what would you expect to happen to the molecules of a material if you removed heat or cooled it? I said, I would think it would move slower. I said, I think of it because if I put water in a freezer, it would be a solid, and solid molecules are slower. They just vibrate. |
| 3-6-U12 | Uma: Yeah. I basically said the same thing. I said I expect they will go slower. |
| 3-6-U13 | Rose : What'd you say for why? |
| 3-6-U14 | Uma: I thought that they would all gain cold energy and slow down, like when water freezes, it turns into solids, which are slow. |

Although both girls made the same prediction, their reasoning was quite different. This seemed to spark a kind of negotiation between the girls in which they clarified, elaborated, and revised ideas, as seen in Excerpt 4.10. This was not observed in the case of Mary and Hannah, despite having not only different reasoning, but different predictions as well. Thus, we see two different ways in which each group "interpreted" the sharing protocol text presented in WeRead. Without more clarity or further support from either the text in the app, or the teacher, the groups had very different types of conversations, each with varying degrees of collaborative discourse.

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One could imagine the potential impact such discourse could have on both the degree to which each student was able to engage with her partner's ideas during the simulation, as well as on their own potential learning process.

The examples from Lesson 6 provided here reinforce our previous suggestion about the need for supports for students to confront and manage conflicting ideas. Mary and Hannah, strictly following the guidance of the *WeInvestigate* text, missed an opportunity to explore each other's ideas behind their different predictions, and in turn may have missed an opportunity for collaborative knowledge building. Rose and Uma's example, in which they had made the same predictions but had slightly different reasoning, supports our recommendation that students also be supported in negotiating similar ideas. Too often in this study we saw students take for granted that their externalized ideas, and the understanding on which those externalizations were based, were the same as their partner's. Instead, we would like to see students supported in pressing each other for their reasoning behind, for example, a suggested contribution to a model.

It is important to note that although the app did seem to support increased student independence, and a freedom to progress through tasks at their own pace, this was not necessarily a goal of ours in developing the app. This finding came about because our teacher-participant purposefully chose to leave the three focal pairs of students more or less alone as they worked together to complete tasks, and increasingly so as the unit progressed. This app was not designed to remove the teacher from the education equation, or minimize her impact, as other educational technology programs are perhaps aiming to do (e.g. Kahn Academy). The app and specific activities had actually been designed with the teacher and her style of teaching partly in mind (e.g., the prompts to "STOP and wait for the teacher"). However, the potential use of such technology to allow students the freedom to explore and progress through lessons at their own

pace in the name of assisting teachers in differentiating and targeting instruction cannot be overlooked.

One of the potential affordances of this, and similar, educational technologies is the capacity to support students and teachers in being able to better differentiate instruction (e.g., Tomlinson, 1999). As we saw in this study, the focal students were able to work more or less independently, thus freeing the teacher up to provide more time and attention to other students, which she did. In order to support the teacher in differentiating instruction using future iterations of *WeInvestigate*, flexibility should be built into the design and pacing of lesson tasks (Rose & Meyer, 2002). For instance, activities that extend the learning of a given lesson can be designed for students moving through the lesson more quickly.

In addition to supporting students' independent progression through lesson tasks, a necessary feature in supporting a teacher in differentiating instruction and pacing in this way is that there are supports built into the app for the teacher to check on students' progress and provide immediate feedback. At the time of this study, the capacity for students' work to be viewed with ease by the teacher, assessed, and feedback provided to students, had not been developed. Our teacher could not even easily observe students' final products. This was, of course, viewed as a limitation, given that an analysis of students' final products sometimes conveyed erroneous and incomplete ideas that went entirely unchecked and unaddressed. In future iterations of *WeInvestigate*, it is mandatory that teachers be given the capacity to easily check students' progress on the tablet in real time, and provide immediate feedback as necessary.

### 5. Conclusions and Implications for Future Work

This paper presented the findings of an exploratory pilot study of 6th graders' use of the *WeInvestigate* app to engage collaboratively in science practices to learn science content. The

findings and discussion in this paper support, and further contribute to the field's knowledge regarding students' synchronous collaboration and knowledge building as they co-construct models and model-based explanations, and more specifically, as they do so within an app-based learning environment. Throughout this study we tried to maintain a strict definition of collaboration (Roschelle & Teasley, 1995), such that it was not assumed that if students were interacting they were collaborating. There were a number of criteria, derived from the literature, that we looked for as evidence of more productive collaboration. More productive collaboration can be identified by the fact that, first and foremost, students listen to and respond to what their peer says (Dabbagh, 2005; Barron, 2003). They are jointly attentive as they develop a shared representation (Suthers, 2005; Barron, 2003; Schwartz, 1995). And, they directly engage with each other's ideas (Kuhn, 2015). For the most part, we did indeed see that the students within a pair were jointly attentive to each other and to the task. Collabrifying paired students' tablets such that they could both participate in the construction of written and drawn artifacts supported the development of shared representations. The degree to which students "directly engaged" with each other's ideas, on the other hand, varied. More often than not, the students did not engage in high-levels of transactive talk, another characteristic of productive collaboration (Teasley, 1997), as they co-constructed artifacts.

The findings demonstrated that the students in this study engaged primarily in coordinative talk to complete modeling and model-based explanation tasks. They did not often engage in explicit content talk, and rarely engaged in high-level transactive talk, to complete these tasks. Thus, the overall picture of student interaction during *WeInvestigate* was one of task coordination rather than collaboration as strictly defined in this study. However, we saw instances of effective collaborative interactions amongst the groups, and the way in which

WeModel, in particular, was able to support students' joint attention to a shared science representation, and students' models acting as mediators of their talk (and vice-versa), highlight the potential of the collabrified technology to support student collaboration as they engage in science practices.

This paper also hypothesized the impact of the collabrified technology and additional designed supports, described in Chapter 3, on students' collaborative interactions. For instance, the collabrified technology and additional designed supports in *WeInvestigate* were able to support students in engaging with their partners to more independently, and with some success as evidenced in part by pre-post- test score gains (Table 4.1), construct models and model-based explanations. Because of the nature of this study, we cannot necessarily make causal links between student behaviors and outcomes and the collabrified technology by itself. However, the differences in collabrification between WeModel and WeWrite provided a kind of natural comparison and examination of the collabrified technology. In particular, the power of the collabrification, especially of WeModel, lie in students, each working on their own tablet, engaging synchronously both face to face and through the tablet, to co-construct artifacts. I suggest that some of the times in this paper when I identified effective collaborative student behaviors as "spontaneous," that is, as not explicitly elicited by any designed support, may actually have been a result of the fact that students could engage with each other synchronously in this way. Hence, I believe further study of the collabrified technology is warranted. However, I also found that more built-in, mostly text-based supports were needed to more effectively bolster the collabrified technology, which I believe has a lot of potential  - if accompanied by the right supports.

Where the collabrified technology by itself seemed to fall short, was in supporting students in effectively eliciting their partner's science ideas, pressing for reasoning, confronting and resolving conflicts (and similarities) in ideas, and asking for and giving content-related help. Furthermore, the evidence presented in this paper suggests that the designed supports, primarily built into WeRead, also did little to support these more highly transactive behaviors and desirable behaviors in students. For example, there were few supports for students' thinking during model construction tasks (and not just during the follow-up after the task has been completed), helping them make more connections between the model and science content or model and phenomenon being modeled. Similarly, although WeRead sometimes provided protocols for students to use when sharing their ideas and discussing similarities and differences (see Figure 4.1a, Figure 4.4), not enough support was provided in helping students identify and manage conflicting ideas. Given all of the findings and our hypothesized connections of those findings to specific collaboration supports, more empirical studies are still needed to tease apart the ways in which the collabrified technology, the directions and prompts, and the tasks themselves contributed to students' collaborative endeavors.

Discussed throughout this paper were implications of this work with respect to design improvements for future iterations of *WeInvestigate*, or similar technologies. In particular, because I suspect that some of our designed directions and prompts may have inadvertently contributed to more coordinative talk, I encourage designers to be mindful of the language used for any directions, prompts, and any scripts or protocols. For example, simple changes in prompts from telling students to "talk with your partner" to telling them to "persuade your partner" may have impacts on the degree and effectiveness of student collaboration. Additionally, some degree of coordination is necessary for students working together to complete tasks; to

support task completion, teachers may want students to be able to "check" that certain components were addressed in a model, for example. A technological environment, such as *WeInvestigate*, has the potential to support teachers in this endeavor while also pushing students to explain their thinking – perhaps through the use of pop-up prompts that do not go away until a response is provided - during the modeling process itself, and not just in reflection-type questions after the modeling process has been completed.

In addition to design recommendations, I was inspired by this work to recommend areas where related and potentially valuable avenues of research may be explored. It is sometimes assumed that if students are interacting they are collaborating. Considered a skill, educational interventions may support students' collaborative endeavors. The collabrified nature of the *WeInvestigate* app necessitated student collaboration, and this collabrified nature was viewed as an intervention with the potential to support student collaboration. As mentioned previously, collaboration has a developmental progression of its own (Tomasello & Hamann, 2012). Realizing collaboration as a progression raises the possibility for studies that contribute to the creation of such a progression, and of the design of educational interventions that support students' progress and/or boost their mastery of the skill  (Kuhn, 2015). The findings from this study have potential implications for our understanding of students' collaborative development in sixth grade and - perhaps more importantly, given the current push for more technology in classrooms (PCAST, 2010) – within a technological learning environment. Noting differences in student talk and collaboration during different types of tasks, such as the ones described here, may contribute to the development of a theoretical collaborative "learning progression," as well as contribute to the design of learning environments that support students' movement along such a progression.

The use of the *WeInvestigate* app in our study context afforded students a vastly different way of engaging with learning and doing science than they had previously known. Working collaboratively, pairs of students, with increasing independence from their teacher as the unit progressed, were able to engage in scientific modeling of some complex science ideas, and showed improvement in their understanding of those ideas. Given the very structured, more traditional, teacher-centered, textbook-based way in which these students learned science, *WeInvestigate* acted to "disrupt" their approach to science (Christensen, Horn, & Johnson, 2008; Sharples, 2003). New curricula and tools, such as the integrated *WeInvestigate* app, must be accompanied by new teaching approaches (Reiser et al., 2001). Therefore, a highly desirable and necessary avenue of future research is the close study of how a teacher enacts science instruction using *WeInvestigate*, including the modifications she makes for her students and context, and in comparison to how she would enact the same unit without *WeInvestigate*.

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**CHAPTER V**

**Conclusions and Future Directions**

This dissertation focused on student collaboration, and how collaborative learning, supported by a model-based science curriculum that was designed to be integrated with and leverage specific functionalities of the collabrified *WeInvestigate* technology, supported peer interactions, and facilitated knowledge building among pairs of sixth grade students. We sought to study the feasibility of embedding an entire well-researched, innovative curricular unit into a single app for use with mobile devices; to investigate the synchronous collaborative capabilities of students using the app to engage in scientific practices; and to study student learning outcomes in a context in which the teacher and students had not previously engaged in teaching and learning science in this way.

The three manuscripts that comprise this dissertation examined sixth grade students' collaboration as they engaged in co-constructing models and model-based explanations through an app-based science unit, *WeInvestigate*. This series of papers described: the design of the app-based science learning environment (Chapter 3), the methodology used for the study of student interactions in this complex learning environment (Chapter 2), and the study of student collaborative co-construction of models and model-based explanations in *WeInvestigate* (Chapter 4). In general, this series of papers provided the following evidence. First, teaching and learning with *WeInvestigate* has the potential to "disrupt" (Christensen, Horn, & Johnson, 2008; Sharples, 2003) traditional classroom instruction, if such a thing were desirable. The students learned science, and were able to engage in collaborative modeling and explanations of phenomena

through their interactions with *WeInvestigate*. Further, they did so generally of their own accord (especially toward the end of the unit) and without significant intervention on the part of their teacher. That students could use the *WeInvestigate* app in these ways and show improvement in their content understanding is particularly notable considering the more traditional context of their science class, which had been very teacher directed, textbook-based, and devoid of much collaboration and technology use.

Second, the collabrified nature of WeModel, in particular, highlighted the potential of the technology to support students' collaborative interactions with each other and the artifacts they co-constructed. The collabrified nature allowed students with linked tablets to immediately see and provide feedback on a partner's contributions. In this way, students' models mediated their talk with their partner, and their talk was able to mediate the co-construction of their models. Furthermore, sometimes students' discourse occurred partly through the models themselves, in the form of drawn externalizations and drawn responses to those externalizations.

Third, the collabrified technology and additional supports in *WeInvestigate* seemed to more often support students' coordinative talk to complete tasks together, rather than their collaborative knowledge building talk around science concepts and phenomena. Thus, there are still a number of modifications to be made to the *WeInvestigate* technology before it can be optimally used in K-12 classrooms to support students' collaborative science endeavors. For example, in general, students did not often engage in high-levels of transactive talk, and their explicit talk about science concepts was consistently low across all lessons for all three pairs of students in this study, more so as they co-constructed models than when they wrote model-based explanations. Further, co-construction of models mostly mediated students' talk with respect to

aesthetic features of the model and task completion, more so than explicit or spontaneous scientific talk and thinking.

Finally, the multiple data sources and methods chosen for this study were sufficient to deeply understand student interactions and potential knowledge building in the complex and unique technological learning environment that was situated within a more traditional classroom learning environment.

Within each of the chapters in this dissertation, findings were discussed and often overlapped and led to similar or related limitations, and implications. This concluding chapter expands upon these considerations and these implications, which are relevant for education researchers, curriculum and learning environment developers, teacher educators and professional developers, and teachers.. Specifically, mirroring each chapter, limitations, or challenges, related to the chosen methodology, the learning environment, and student outcomes will be discussed. Although this study did not explicitly focus on teacher outcomes, our collected data and anecdotal observations led to implications related to teacher implementation of *WeInvestigate* that will also be discussed.

## Methodological Limitations and Implications

The collection of multiple data sources and use of multiple analytical methods for this study of students' collaborative knowledge building discourse within a mobile digital learning environment, provided information about the "what" and the "when" of the student talk, as well as a description of "how" this kind of collaborative discourse occurred, as demonstrated by examples in each of the three papers presented in this dissertation. Rich cases (Merriam, 2009) were developed which detailed how each of the three pairs of students sampled for the study engaged with each other and the *WeInvestigate* app to collaboratively construct artifacts of their

learning and build knowledge within the learning environment. The analyses and case development allowed for immersion in the data, and for attainment of a deep understanding of the social context and interactions of the student participants. However, the chosen methods also had their limitations, which resulted in implications for the design of similar research investigating student interactions in face-to-face technological learning environments.

One limitation in this study arose from the data collected. The technological environment, at the time of this study, was such that we were only able to collect screenshots of students' final co-constructed products, rather than shots of their artifact construction process. Given our purpose - to examine and understand processes by which students were able to collaborate and learn within a complex technological environment - we not only needed information about students' verbal interactions with each other, as collected via audio recordings, but also documentation of their interactions with the artifacts they produced. We know from students' talk and the log files that often quite a bit of work, and several revisions, went into the production of students' final artifacts. Although in most cases we had evidence from their talk to make some strong assumptions about the degree to which each student's suggested contributions ended up in their final products, we could not know with certainty what was drawn/written, or who drew/wrote it.

This gap in the data we were able to collect was compounded when the students did not verbalize the ideas that were entered into the final artifact. In these instances, we had students' final artifacts, but had very little in terms of verbalized discourse on which to derive an analysis of how the artifact was produced by both of the students involved. Our ability to sufficiently analyze student talk, in conjunction with the artifacts simultaneously co-constructed by the students, was also made more challenging when some of the students' discourse occurred

through the artifact itself. Although we saw this phenomenon occur with all three groups at different times in our study, we highlighted examples from Mary and Hannah's case in Chapter 2 (Excerpt 2.1) and Chapter 4 (Excerpt 4.6). Additionally, we saw instances in which students spent large amounts of time discussing and generating a model or an explanation that was later "lost" by the technology, requiring them to reproduce their artifact (the final one being the one to which we had access). In doing so, they – understandably -  generally engaged in much less talk.

Stemming from the above-described limitations in the data we were able to collect, was a limitation in how our coding framework could be applied to the verbal data. The coding framework chosen for the quantitative content analysis in this study was primarily derived from coding frameworks found in the literature (Weinberger and Fischer, 2006; Gijlers and de Jong, 2009; Gijlers et al., 2013). These frameworks arose out of many studies on students' collaborative learning within CSCL environments, and were based also on the previous work of others who studied collaborative discourse more generally (e.g., Oliveira & Sadler, 2008; Hogan, Nastasi, & Pressley, 1999; Teasley, 1997).  Common themes in the ways in which these and other researchers characterized students' collaborative discourse (e.g., idea convergence; disagreement/challenges to ideas, presenting and elaborating on ideas, negotiation) validated the choice of the coding framework used in this study to analyze students' collaborative discourse in the context of a face-to-face and synchronous technological environment. Moreover, for the most part, the coding framework did meet our coding needs and appropriately characterized students' talk, including what they were saying to each other, and how they were interacting with each other.

However, interaction analysis revealed that some of the interaction between the students occurred through, and was mediated by, the co-constructed artifact, as stated previously. The

"talk" that occurred less explicitly through model drawing, for instance, was often not considered according to the coding framework used, unless it represented an explicit instance of that kind of talk. Because of this, it is possible that the transactive talk codes in our coding framework may have been under-applied to talk that was more collaborative than it would have seemed, such as we saw in the case of Mary and Hannah (Chapter 2, Excerpt 2.1). Although our coding framework could have been applied to this discourse that occurred through the model, because we had only collected the final product and did not have access to the modeling process, this aspect of the students' talk more or less went unrecognized in the quantitative part of our analysis. This meant that, in addition to under-coding with respect to the transactive talk codes, there was a discrepancy between what had been coded and counted based on the utterances alone, versus what was uncovered via qualitative consideration of the utterance context, as well as what the students were actually doing at the time of the utterance.

These limitations, both in the data collected and how they were analyzed, speak to several methodological implications for researchers interested in examining the processes and mechanisms by which students undertake knowledge building around the collaborative co-construction of artifacts. First, up to one-third of students in any given class at any given time may be considered "silent" students (Jones, 1990) – students who do not engage much in classroom interactions. Because these types of students exist in every class, and it is the teacher's responsibility to manage their learning, it is important that these students be considered and included in studies (Jones & Gerig, 1994) on student collaboration, even though it may result in challenges for data collection and analysis. Thus, it is up to researchers to be creative about how to get at these students' thinking and the ways in which they may or may not participate in collaborative artifact construction via less verbalized discourse.

Further, the prevalence and relative ease of use of screen capture technology (e.g., Jeong, 2013; Zahn et al., 2012; Suthers & Medina, 2011) on mobile devices would allow for data collection and analysis of the process of an artifact's development, not just the final product. The use of screen-capture technology, analyzed in conjunction with students' talk, would provide more access to the nature of students' contributions to products, which would be particularly important when students do not explicitly verbalize their ideas. Furthermore, an appropriate transactive talk code could be applied and factored into the analysis.

In addition to the use of screen capture technology, another way to try to get at students' individual and collective thinking would be to conduct periodic student interviews. For instance, in addition to the use of screen capture in their study of expert models and modeling processes associated with the Model-It software, Zhang and colleagues (2006) interviewed participants to further probe the rationale of their modeling practices. Similar interviews could be conducted with students in a future study of *WeInvestigate* in which individual and paired scientific thinking about the artifacts they constructed could be collected. Such data would be particularly useful for learning about more "silent," or at times less verbally participatory, students.

The complexity of this study meant that a lot of data were collected, and analysis was very time consuming – perhaps unavoidably so. The use of screen capture technology and student interviews would mean adding more data and thus more time required for analysis. More focused sampling with the assistance of tracers (e.g., Beyer & Davis, 2009; Roth & Roychoudhury, 1993) may help. Tracers, defined as a "bit of knowledge" (Newman et al., 1989), were used in this study in an attempt to examine potential knowledge building over time during student interactions.  In our study, a number of criteria, described in Chapter 2, dictated what lessons and lesson tasks were chosen for transcription, coding, and further analysis. However,

this may have limited our ability to effectively see evidence, via content tracers, of student knowledge building over time. Designing the learning environment in such a way that would support eventual tracing of student knowledge throughout a unit would help support researchers in more effectively identifying lessons and tasks to be sampled, depending upon what content knowledge one is interested in tracing.

However, the use of tracers also exposed another limitation in our data, or rather the overall study design. As we designed the *WeInvestigate* learning environment, we had not anticipated the eventual use of tracers as a means to examine potential knowledge building over time, and found it challenging to find evidence of students' thinking about specific content that could be traced throughout the unit (i.e., beyond just seeing it on the pre- and post-tests). Additionally, there was some content for which there was more evidence - because there had been greater emphasis on it in the unit, and by the teacher - while for other content there was little. For example, there had been heavy emphasis placed on what was happening to molecules in solids, liquids, and gases at a nano-level, but less emphasis on connecting this behavior at the nano-level to observations at the maco-level. Actively building the potential for content tracers into the design of prompts meant to elicit student thinking, and doing so with coherence and consistency for the desired content, across the unit, may help researchers – and teachers - study student knowledge building over time in similar complex collaborative and technological contexts. In other words, designing learning environments in this way would not only be methodologically beneficial for researchers, but may also allow for teachers to study their students' progress in very concrete, data-driven ways.. Tracers have the potential to reveal information about the evolution of thinking, when examined over time.

In order to fully understand student collaboration and the conditions under which it can be considered productive, it is necessary to understand the underlying mechanisms of the collaboration (Kuhn, 2015). To understand the underlying mechanisms of collaboration, group interactions must be deeply examined. However, this is rarely done because it is time and labor intensive, as described previously (Howe, 2010). Therefore, studies such as the one described in this dissertation, which used multiple data sources and methods to understand the collaborative processes of knowledge building and co-construction of artifacts via a technological learning environment, remain important avenues for research.

## Learning Environment Implications and Limitations

One of the findings from our close study of student collaboration and the *WeInvestigate* app was that the app provided students with a degree of independence (from their teacher) as they progressed throughout the unit. While text found in WeRead included the directions and guidance to support this, it was not necessarily a goal of the design team that students should progress on their own through the lesson tasks. However, this finding exposed not only the ways in which *WeInvestigate* was able to support students' independent progress, but also the ways in which it fell quite short of supporting students' more independent learning with the app and from each other. As a result, improvements to the app, primarily centered around better supports for student knowledge building and collaborative discourse through the use of *WeInvestigate*, are suggested.

Many of the findings related to students' interactive talk may have been a result of structures (or lack of) designed to support collaboration within the *WeInvestigate* app. For instance, our findings that students engaged primarily in low-level transactive talk and coordinative talk imply that the collabrified technology and accompanying collaboration

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supports built into the design of *WeInvestigate*, as discussed in Chapter 3, were unable to consistently and effectively support the more desirable collaborative content-based talk as students engaged in consensus building negotiation of ideas through modeling tasks. The extent of the guidance (scripts, prompts and directions) provided in *WeInvestigate* for students during model construction tasks seemed to be more related to helping students actually construct the models, than on helping them collaboratively make connections between the model and the phenomenon, or the model and science concepts. Guidance for making these kinds of connections was generally provided after students had the opportunity to construct their model, and was usually in the form of question prompts or directions to explain, which students responded to in WeWrite.

Additionally, although the *WeInvestigate* app was easy for students to learn and use, navigation between modules was clunky at times because they were not directly linked to one another. Instead, modules had to be opened and closed as needed, and as dictated by the directions in WeRead. These directions in WeRead did not support students in taking advantage of the split screen capability of *WeInvestigate* to support them in making connections across modules – and thus across modeling and explanation tasks. This may have led to missed opportunities to reinforce key connections among the science content, the model, and phenomena. It may also have led students to approach lesson tasks for the purpose of completion, rather than supporting their deep understanding of these connections. That students in this study seemed more likely to approach the modeling tasks in terms of their completion rather than as a way to deeply engage with science concepts, which may have led them to engage in more coordinative talk, and less high-level transactive talk, described previously.

The combination of these related findings imply that there is still some room for growth in the design of the app with respect to students' more collaborative use of the collabrified modules, split screen, and other designed supports to make connections between the science content, models, and phenomena in the unit. *WeInvestigate* may be re-designed, as discussed in Chapter 4, to better support students' more consistent and authentic use of the app, and include other technological features to better support current reform efforts that include collaboratively developing and using explanatory models.

One of the main affordances of the *WeInvestigate* app was its collabrification feature. We saw a great deal of evidence in this study that the power of the collabrified technology was observed when one student could immediately see and respond to what his or her partner was drawing (or typing). This was true for WeModel tasks more so than WeWrite tasks, unless students verbalized as they typed (e.g., Chapter 4, Excerpt 4.7). In WeModel, even when students were not always verbalizing as they drew, some of the discourse, and negotiation, between students, happened through the drawing itself as students would modify each other's drawn externalizations (e.g., Chapter 4, Excerpts 4.5 and 4.6). This same flexibility for real-time interaction through the co-constructed artifact was not present in WeWrite, due to the delayed synchronicity of that module. Thus, while we did see a number of different ways in which students interacted with each other as they worked together in WeWrite to compensate for this difference, we did not observe the same capability of WeWrite to support interaction through the written artifact as we did with WeModel. It is hypothesized that the difference between the synchronicity of these modules, as well as the ability of both students to work simultaneously on the written product, could explain the observed differences in students' collaboration and potential knowledge building within these two modules. Following this, we suggest exploring the

possibility that WeWrite be redesigned such that it becomes fully collabrified like the WeModel module, and then undergoing another study of student collaboration within these two modules.

However, we also had evidence that suggests that students' interactions during WeWrite tasks may have resulted in benefits for students' knowledge building. We observed somewhat higher amounts of explicit science content talk, and high-level transactive talk during WeWrite tasks when compared with WeModel tasks (Chapter 4, Tables 4.4 and 4.5). We also saw at least one instance in which, because students' science ideas were more explicitly shared during WeWrite tasks, a student directly confronted another student's incorrect idea, such that the student seemed to revise their thinking as a result (Chapter 4, Excerpt 4.7). We did not observe these things as much during WeModel tasks, so in any future iteration of *WeInvestigate*, or similar technology, there need to be supports that explicitly help students to elicit their partner's ideas, share their own ideas, and engage in negotiation around those ideas.

Before students successfully interact with and use built-in supports for collaboration, however, they need a sense of what productive collaboration looks like in general, what productive collaboration looks like in a science context, and some model behaviors or techniques they can use to engage with each other's science ideas. Future iterations of *WeInvestigate* may include videos of students engaging in productive collaboration around science concepts as models for students. Sentence starters for how to elicit and respectfully respond to each other's ideas may also be included. Further, students will need extensive support, and training, to shift their thinking about what counts as an "answer" in science, and to support their use of the technology to help them provide more scientifically authentic "answers." We found that simply telling students to "collaborate" to "explain" was not enough to support students to collaborate in scientifically authentic ways to model and explain phenomena. Instead, we found that they

approached tasks in terms of their completion, and if they completed the task, to their thinking, they had successfully collaborated. This is a "business-as-usual" approach to producing correct answers in schools, and one in which, by sixth grade, students had already been enculturated. A more scientifically authentic approach to tasks would require that students accept that the process of producing "answers" is in many ways more important than the product, and where the learning happens, that the product itself is impermanent, and subject to revision as more is learned, and that the ideas of others are valuable and necessary for producing "answers" that are closer approximations of reality than would have been produced individually. This is a very different approach - to consider what counts as an answer in science versus what counts as an answer in school – and one that requires a more transformative approach to the design of technology than was produced in this iteration of *WeInvestigate* in order to support.

There is evidence that prompts for students to "argue" or "persuade" may have knowledge building benefits for students (Asterhan & Schwarz, 2007; Garcia-Mila et al., 2013). However, these prompts may still be at the level of simply telling students to "explain," and may not provide enough detail or support for students to engage in negotiation around their ideas. There is also evidence that both generic supports, which support students' understanding of a general framework such as the claim, evidence, reasoning framework, and context-specific supports, which provide students with hints about the task and what content knowledge to incorporate into their products are important supports in successful learning environments (McNeill & Krajcik, 2009). While *WeInvestigate* did include context-specific supports, it did not include many explicit generic supports for students. To that end, future iterations of *WeInvestigate* should include prompts in which students are not just asked to "explain," or "argue," but to make claims, support claims with evidence, and justifications. Partners should be

encouraged to rebut each other's arguments. Further, the technology should be designed around these types of supports, as described below. Therefore, embedding more scripts and prompts - and ones that are more focused on students' science ideas, in addition to helping them complete tasks - may help support students' more effective collaboration.

There is evidence from a study on e-text supports (Dalton & Palincsar, 2013) that interactive features, such as supports linking prose and diagrams, or models, which can be manipulated by students, have more benefits for student learning than "static" supports such as a glossary with hyperlinks, which was similar to what was included in *WeInvestigate*. Thus, more interactive features, such as pop-up windows (e.g., Linn et al., 2003) can be embedded in all modules in *WeInvestigate* with prompts such as the ones just described. In the iteration of *WeInvestigate* used in this study, pop-up windows were only possible in WeRead, and were not used to prompt students or provide guidance. The pop-ups – or something similar – may be designed to better elicit students' thinking and support them to engage collaboratively around science ideas through confronting and managing similarities and differences in ideas. For example, perhaps students would be better supported in thinking about the science concepts demonstrated in their models if they were prompted to explain parts of their model as they drew (for an example, see Gijlers et al., 2013).

Additionally, given that we did not often observe students making model-science concept or model-phenomenon connections, in future iterations of *WeInvestigate*, students should be more encouraged and supported to use multiple modules in the service of each other more often, and to integrate their knowledge across the various app features (Linn et al., 2004). This may be better supported through hyperlinks, or some other means of connecting the modules to one another, and may make navigation between "pages" in WeRead and other modules more

streamlined. More effectively and explicitly linking the modules to each other, rather than having students navigate to them separately, may provide some grounding for the cross-module use.

In order to remind students of their purpose for engaging with text, models, and other *WeInvestigate* tasks, the text, including any pop-up prompts, should include more opportunities for students to individually and collaboratively reconnect with and reconsider the personally relevant driving question of the unit (Linn et al., 2004; Blumenfeld & Krajcik, 2006; Blumenfeld et al., 1991). In this study, the teacher had been responsible for supporting students in revisiting the driving question, and helping them make connections between what they were learning, their own experiences, and the driving question. During implementation, however, we did not often see her do this, and wonder if this task should have been better supported in *WeInvestigate*. This type of reflection can also be done via pop-up windows or prompts in WeWrite. Such reflection on the driving question, may further support students in making connections between the models they construct, the science concepts they explore, and the phenomenon.

With these types of technological and textual supports in the app, it is hypothesized that students would be better positioned to make connections among science content, models they co-construct, and the real-world phenomena about which they are learning.

### Student Outcomes and Future Work

Students learned in this study, as evidenced by their pre-/post-test score gains, shown in Chapter 4 (Table 4.1). Our qualitative analysis also found additional evidence of growth in students' science knowledge. As ours was a primarily qualitative, exploratory study, we cannot necessarily attribute these student outcomes to students' collaborative efforts and interactions with their partner, or to any specific feature of the *WeInvestigate* learning environment. Instead, we frame the following discussion in terms of the ways in which our student-based findings

support, and further contribute to the field's knowledge about students' synchronous collaboration and knowledge building as they co-construct artifacts.

Kuhn (2015) and others (e.g., Tomasello & Hamann, 2012; Henderson & Woodward, 2011; Crook, 1995, 1998) have noted that collaboration, similar to students' science content learning, follows a developmental trajectory, which continues to warrant close study by researchers and teachers alike. These studies, however, focused on studying the collaboration trajectory, or "learning progression," of very young children, up to three years old. To my knowledge, no one has undertaken this research with  school-age students. The following reviewed findings have potential implications for our understanding of students' collaborative development in sixth grade, and within a technological learning environment. Thus, these findings also provide concrete examples that may contribute toward the development of a theoretical collaborative "learning progression" for older students.

In reviewing the literature in preparation for analysis in this study, consistent conclusions across multiple studies of student collaboration were found. We utilized these consistent conclusions, which characterized more and less successful, or productive, student collaboration, in our qualitative analysis of students' paired discourse in this study. Thus, did we also find in our own data, instances that supported the persistence of these research findings within a technological learning environment. These will be briefly discussed.

More productive collaboration can be identified by the fact that, first and foremost, students listen to and respond to what their peer says (Barron, 2003; Dabbagh, 2005). They are jointly attentive as they develop a shared representation (Barron, 2003; Schwartz, 1995; Suthers, 2005), and they directly engage with each other's ideas (Kuhn, 2015). Included in our coding framework (Chapter 2, Appendix 2.A) was a "no reaction" code. The fact that the "no reaction"

code, in general, was low across all the groups for all sampled lessons (see Table 4.2 in Chapter 4) meant that, when a student attempted to elicit a response of some kind from their partner, he or she did receive it. In other words, for the most part, the students within each pair listened, and responded, to what their partner said. Further, collabrifying paired students' tablets such that they could both participate in the construction of written and drawn artifacts, especially in WeModel, supported the development of joint attention to shared representations, as most of the Excerpts in Chapter 4 showed.

The degree to which students "directly engaged" with each other's ideas, on the other hand, varied. More often than not, students responded to each other's ideas in the form of "quick consensus," than more deeply engaging them via "integration" or "conflict consensus" (Chapter 2, Figure 2.1; Chapter 4, Table 4.2). In other words, the students did not often engage in high-levels of transactive talk, another characteristic of productive collaboration (Teasley, 1997), as they co-constructed artifacts. Therefore, instances in which students engaged in consensus-building discourse were rarely observed, implying that they generally struggled with confronting and managing both conflicting and similar ideas, both of which have the potential for knowledge building.  Conflicting, or opposing, ideas are seen as an essential component of collaborative discourse, and one that propels it forward (Kuhn, 2015; Schwarz et al., 2000).  A few examples of this phenomenon were found in this study (e.g., Chapter 4, Excerpts 4.5, 4.7). We also saw, to a much lesser degree, instances in which Rose and Uma engaged in a kind of negotiation when there was general agreement about an idea (e.g., Chapter 4, Excerpt 4.10). While this kind of spontaneous "integration consensus" interaction seemed to be more a function of these girls' personalities (Muldner, Lam, & Chi, 2014; Sears & Reagin, 2013), it demonstrates students' potential to engage in both kinds of consensus-building discourse.

Because collaborative tasks often involve many different parts, or activities, that need to be done, the need for coordination of the task arises (Erkens et al., 2005). Findings in this study support the assertion that coordination is an important and necessary part of the collaborative process (Roschelle & Teasley, 1995; Palincsar & Herrenkohl, 2002). Coordination in this study was defined as talk that focused on the coordination, planning, and monitoring of the learning task (Gijlers et al., 2013). Coordinative talk consistently comprised the highest percentage of students' on-task utterances across all sampled lessons. Additionally, students relied more on coordinative talk to complete model construction tasks than they did model-based explanation tasks.

It was shown in Chapter 2 (Figure 2.2), and Chapter 4 (Tables 4.4 and 4.6) that especially during model construction tasks, students' explicit talk about science content or about science phenomena was very low overall. Moreover, instances in which the content or phenomenon talk co-occurred with talk about the model as it was being constructed were even lower, implying that students were not making many model-content or model-phenomenon connections. Similar previous findings have noted, for example, that students, when compared to experts, both working in the field of chemistry, did not make connections between, and use models to help them think and reason about nano-level explanations for macro-level observations (Kozma, 2003). Similarly, students often find it difficult to make connections between molecular explanations and visible phenomena (Stavridou & Solomonidou, 1998). Given a goal of NGSS (NGSS Lead States, 2013) and the Framework (NRC, 2012) to have students engage in authentic science practices, which include making model-concept and model-phenomenon connections, these findings are problematic.

While education researchers and practitioners alike generally see the potential benefits for their students by having them collaborate with their peers, it has also been found that collaboration is not always beneficial for all students (Kuhn, 2015; Webb & Mastergeorge, 2003; Weinberger et al., 2005). In addition to the above characteristics of more productive collaboration, whether or not collaboration will be beneficial for students also appears to depend on who is learning what, and under what conditions they are learning  (Kuhn, 2015). Some students may not benefit at all from engaging collaboratively with their peers (Sampson & Clark, 2009). Thus, we also found in our study times when the students were engaged in less productive collaboration. In instances of less productive collaboration, students worked in parallel and ignored or dismissed their partner's contributions (Barron, 2000). This kind of interaction occurred most often in the cases of Quentin and Marcel, and then Quentin and Omar (e.g., Chapter 2, Excerpt 2.5, Excerpt 2.6).

We also observed instances in our study in which the quality of the jointly-created product was more attributable to one member of the group (Schwartz, 1995), particularly in cases where students were given individual think time first, as in Lessons 1 and 12. This dominance of one member of the group may be due in part to student personalities (Mulder, Lam, & Chi, 2014; Sears & Regin, 2013). In other cases, it may also be due to the content-related confidence of the students involved, with the less confident student deferring to the more content confident one.

Thus, there was evidence in this study that the students did engage collaboratively with each other as they co-constructed artifacts, according to the characteristics, and our definition, of productive collaboration. Though there did appear to be some notable differences in the students' talk during different types of tasks (e.g., WeWatch and simulation tasks vs. WeWrite and model construction tasks, Chapter 2, Figure 2.2), our interest in this study was focused on model

construction and explanation writing tasks, per current reform efforts in science education (NGSS Lead States, 2013; NRC, 2012). The example model construction and explanation writing tasks presented in this dissertation show, too, that there is still much room for growth in supporting students' more effective collaboration around these tasks through *WeInvestigate*. They also highlight the potential of *WeInvestigate* as a way for students to engage collaboratively in these types of tasks. Future work should not only explore how to modify future iterations of *WeInvestigate* to better support productive student collaboration and science knowledge building during these types of tasks, but researchers may also be interested in how and why students engage in these tasks differently than how they engage with simulations, or when observing a video or animation, for example. In this study, we could only hypothesize reasons for the differences between student collaboration in different tasks, therefore, more experimental and comparative studies may be warranted. Noting differences in student talk and collaboration during different types of tasks may also contribute to the development of a collaborative "learning progression" and our understanding, per Kuhn's (2015) article, of, "When does collaboration work?" and, "What is the role of the task around which students are asked to collaborate?"

Few studies have been done at the deep level of analysis of student-student and student-technology interactions as was done in this dissertation (although see Looi & Chen, 2010, for a study on elementary students' synchronous interactions as they worked to collaboratively solve a single math problem in Group Scribbles, a general purpose technological environment). Thus, more studies of student discourse that occurred through artifact co-construction – such as was observed in this study - for other technology-based learning environments, and for other age groups, are still needed to advance our thinking about student collaboration in technology-based

science learning environments, and could also provide potential contributions to this "learning progression."

Many of these student-based findings support previous collaboration research, both with and without the use of technology.  This may imply that the ways in which students collaborate face-to-face with and without synchronous technology are similar. However, as a primarily qualitative, exploratory study, we cannot make claims about differences between students who collaborate in a technological environment and those who do not. Thus, a comparative study of students' collaborative use of the *WeInvestigate* curriculum with and without integration into the app environment would be an area of fruitful research. We also wonder about the similarities and differences between students' collaborative interactions in other science contexts, as well as non-science contexts, within a similar technological environment.  More experimental studies such as these that may further contribute to a collaboration "learning progression," and also our understanding of the potential of the collabrified technology to advance students along such a continuum[18].

All of these findings suggest that the students in this study were novice collaborators and generally remained so throughout the unit. These findings also demonstrate the variation in the ways in which the students in this study engaged in productive collaboration, as characterized by previous research. This variation may simply be a natural outcome of when individuals attempt to collaborate. Some of the observed differences between students' collaboration and knowledge building while using the WeWrite and WeModel modules may have been due to the tasks themselves. They may also be due, at least in part, to the fact that aside from the collabrified technology and some built-in supports, there was generally little internal or external support for

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[18] A comparative study of students engaged in the *WeInvestigate* curricular unit with and without the app is, in fact, a study that the *WeInvestigate* research group undertook in the 2014-2015 school year; work in progress.

students engaging in consistent and productive collaboration during modeling tasks in *WeInvestigate*, as discussed in Chapter 4. Thus, the findings in general may have been a result of the design of the learning environment, discussed in the previous section. Hypothesizing about the additional supports for collaboration that would be necessary in a learning environment such as *WeInvestigate*, was one of the goals of this study.

**Challenges and Implications Related to the Teacher and *WeInvestigate* Implementation**

*WeInvestigate* was not necessarily designed for use without a teacher. In fact, it was designed with our specific teacher-participant in mind, and with the assumption that a teacher would be necessary, even in a technology-based classroom.  Although, as this study found, students were able to progress more or less independently of their teacher through lesson tasks using *WeInvestigate*, and learn as they did so, our findings also support, and thus we still maintain, that teachers are necessary to guide, support, and provide timely feedback for students as they engage with each other and the technology. Though this study did not explicitly collect or analyze teacher data, our collected data and anecdotal observations have implications for future iterations of *WeInvestigate*, as well as for teacher education and professional development.

There were many anecdotally observed challenges associated with teaching with *WeInvestigate*. We also observed the potential challenges we would anticipate teachers using such technology in their classrooms to have. All of these have been noted in prior research. Perhaps the biggest challenge we observed was with managing the technology, while also attempting to manage the students (Becker et al., 1999). As noted in Chapters 1 and 2, our teacher-participant, Ms. Jones, was an inexperienced technology user, and did not often use technology with her students. When she did, it was - more often than not - her using the technology while her students watched (e.g., PowerPoint presentations, or simulation

demonstrations). Implementing science instruction with *WeInvestigate* came with a steep

learning curve for Ms. Jones. Each one of the 28 students in her class had their own 7" tablet and

stylus. For individual work they had paper workbooks and their writing utensil. Managing these

materials themselves (e.g., developing a system for charging the tablets overnight, distributing

and collecting materials in class each day) was only part of her challenge. The unreliability of the

technology (Becker et al., 1999) inevitably arose, with at least one student having a problem with

his or her tablet each class period. These problems ranged from a simple fix that a peer could

assist with, or Ms. Jones could handle herself (e.g., the student navigating to the wrong place), to

more complex problems that required a technology specialist (e.g., coded error messages related

to information being sent back and forth to the cloud).

Other management challenges for the teacher related to pacing. Initially, Ms. Jones tried

to keep her students moving along through the lessons at the same pace. She closely adhered to

the suggested guidance in *WeInvestigate* regarding where she should stop and regroup the

students for a discussion. She eventually saw that some students could progress further on their

own, while others needed more personalized support and guidance from her. Consequently, Ms.

Jones gradually allowed certain groups the freedom to progress through *WeInvestigate* lessons at

their own pace, and toward the end of the unit groups were working on different lesson tasks at

different times, another management challenge noted by Becker and colleagues (1999). While

this different pacing may have better met individual student's or pairs' learning needs by either

progressing more independently through tasks, or receiving more individualized support from the

teacher, this resulted, in part, in some off-task behaviors that required further management,

another challenge of using this technology.

Though not purposefully included in this iteration of *WeInvestigate* for this implementation, we see this potential of the *WeInvestigate* app to support differentiated instruction (Tomlinson, 1999) as an affordance of the technology. Other studies of student learning with technology have demonstrated this capability with other technologies. For example, Kara-Soteriou (2009) described how teachers could utilize different types of technology (e.g., websites, SMART boards) to differentiate instruction across content areas. Larson (2010) found that two 2nd graders' use of a Kindle differentiated reading instruction by providing them individualized reading support. CSCL environments not only have the ability to impart new skills and abilities to students, they can also support more effective instruction on the part of the teacher (Urhahne et al., 2010). Thus, this finding has implications both for the design of future iterations of *WeInvestigate* and also for teacher education and professional development.

In order to support the teacher in differentiating instruction using *WeInvestigate*, flexibility should be built into the design and pacing of lesson tasks (Rose & Meyer, 2002). For instance, activities that extend the learning of a given lesson can be designed for students moving through the lesson more quickly. In addition to supporting students' independent progression through lesson tasks, a necessary feature in supporting a teacher in differentiating instruction and pacing in this way is that there are supports built into the app for the teacher to check on students' progress and assess and provide immediate feedback as necessary (e.g., a "teacher portal," or a way for students to formally "submit" work-in-progress). At the time of this study the capacity for students' work to be viewed with ease by the teacher, assessed, and feedback provided to students, had not been developed. Ms. Jones could not even easily observe her students' final products. This was, of course, viewed as a limitation, given that an analysis of students' final products sometimes conveyed erroneous and incomplete ideas that went entirely unchecked and

unaddressed in their work. In future iterations of *WeInvestigate*, it is necessary that teachers be given the capacity to easily check students' progress on the tablet in real time, and provide feedback.

In addition to learning to teach in new ways with technology, Ms. Jones was simultaneously asked to engage in a different approach to pedagogy than she was previously accustomed to. As described in Chapter 3 the *WeInvestigate* unit in this study was adapted, in part, from the inquiry-driven, science practice-based IQWST Smells unit (Krajcik et al., 2013). Ms. Jones' pedagogical style was very teacher-directed, textbook-based, and very different from the style required by the *WeInvestigate* curricular unit. Instruction with curricula such as the one embedded in *WeInvestigate* is more time consuming, and requires a more active role on the part of the teacher (Crawford, 2000; Blumenfeld et al., 1991). This, compounded by the more time-consuming nature (at least initially) of teaching with technology, led to issues of time management (Hew & Brush, 2006).

Mentioned previously, it was observed that students in this study did not often make connections between their models, phenomena, and science concepts, and when they did so, it seemed to be spontaneous – that is, not explicitly supported by anything built into the app. The teacher's own lack of experience or comfort level with the type of curriculum in *WeInvestigate* may have resulted in missed opportunities to better support students in making those connections. For instance, in order to support curriculum coherence (Shwartz et al., 2008), the teacher's guide included suggested places for the teacher to refer back to the phenomenon and the driving question of the unit. The teacher's guide also included some support for the teacher to engage her students in discussions around the driving question. However, these kind of synthesis discussions were not often taken up by the teacher during the unit, and were not included anywhere in the

app. Perhaps as a result, students had fewer explicit and guided opportunities to make connections between what they were learning and the driving question.

Many of the technology-related issues were alleviated somewhat as researchers, and sometimes technology specialists, were present in her classroom everyday throughout the study to support her implementation as necessary. However, these issues and others - such as schools having sufficient wireless internet infrastructure (Zhao et al., 2002) to support entire classes of students sharing information synchronously through the cloud - are relevant and must be considered not only by researchers wishing to study classroom technology use, but also by teachers, schools, and districts as they move toward adoption and use of these technologies.

In order to effectively teach and support students using a pedagogically forward-thinking app-based science curriculum such as *WeInvestigate*, teachers need to have strong knowledge of their content, and pedagogical content knowledge to implement the more demanding curricula. This knowledge also needs to be integrated with a strong technological knowledge to develop an overall technological pedagogical content knowledge (TPCK, TPACK) (Guzey & Roehrig, 2009; Harris et al., 2009; Harris, 2008; Niess, 2005). TPACK is a form of professional knowledge in which teachers' understandings of technology, pedagogy, and content interact with one another to produce effective discipline-based teaching with educational technologies (Harris et al., 2009). For example, teachers with strong TPACK know pedagogical techniques that incorporate the use of technology to appropriately teach content in differentiated ways according to students' learning needs. They also know, for instance, what is challenging about their content area and how technology can be used to address those challenges. Given the increased complexity of teaching with the more pedagogically demanding reform-based curriculum and collabrified technology, not only are there potential implications from this study for teachers themselves, but

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also for teacher educators and professional developers who will have the task of supporting pre- and in-service teachers in integrating technology-based science instruction (Barton, 2005).

It has been demonstrated that curriculum materials with opportunities for students to engage in science practices, such as the *WeInvestigate* unit, have a positive impact on teaching and next generation science learning outcomes (Harris et al., 2014). Further, research-based curriculum materials that include supports for teachers to help their students participate in science practices can impact the teaching practices of teachers (Harris et al., 2014). Similarly, during our study of *WeInvestigate*, we did observe some changes in Ms. Jones' approach to instruction, but these were mostly related to her allowing students to progress more independently through tasks, than a cultural shift in how she approached engaging her students in the science practices in more scientifically authentic ways. Although the curriculum materials adapted for use in *WeInvestigate* did include opportunities for students to engage in science practices, and although there were some supports in the teacher's guide, more could certainly have been done to support the teacher in providing a more authentic science-as-practice context in which to participate in learning with *WeInvestigate*. However, shifting teacher orientation related to the nature of science and inquiry warranted in classrooms is not easy, and usually requires extensive professional development, particularly when a teacher is at the end of his or her career - as was Ms. Jones – and does not have the same motivation to change her orientation as does a teacher beginning her career. This raises the question of whether *WeInvestigate*, or similar technologies, could be designed to engage students in effective collaboration and next generation learning, regardless of the teacher's orientation or the pre-existing classroom culture.

A noted mismatch exists between educational technology leaders' visions for technology integration, and how technology is currently being used by most teachers (Culp, Honey, &

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Mandinach, 2003). Namely, educational technology researchers envision technologies used to support inquiry, collaboration, and pedagogically forward-thinking practice. Many teachers, on the other hand, focus on using technology for presentation, learner-friendly websites, and management tools to supplement existing instructional practice (Culp et al., 2003). The teacher in this dissertation study had rarely used technology in her class, but, when she did, she did so in similarly supplemental ways. It is notable, therefore, that, despite the many encountered challenges described above, and without any professional development prior to engaging in this study, through her use of *WeInvestigate* Ms. Jones: (a) engaged in a pedagogically different teaching style than her own, in which students were expected to collaborate, (b) used technology for instruction when she had rarely done so before, and (c) did so fairly effectively, such that the students demonstrated knowledge gains. In this way *WeInvestigate* worked to "disrupt" (Christensen, Horn, & Johnson, 2008; Sharples, 2003) the traditional classroom structure. This unanticipated finding warrants further investigation. Studies of teachers' roles in such environments, especially as more app-based learning environments for mobile devices are developed, are relatively few in number (e.g., see Urhahne et al., 2010 for a study of teachers' role in CSCL environments), and are a particularly fertile area for research.

## Contributions and Outlook

Taken together, the three manuscripts presented in this dissertation provided encouraging evidence regarding the potential of teaching and learning with *WeInvestigate* to "disrupt" (Christensen, Horn, & Johnson, 2008; Sharples, 2003) traditional classroom instruction; the collabrified nature of *WeInvestigate* to support students' collaborative knowledge building and co-construction of artifacts; and the potential of the methods used for future studies of this nature.

The findings presented in this dissertation are intended to contribute in theoretical, methodological, and applied ways to the fields of science education, educational technology, and the learning sciences. Specifically, the findings in Chapter 2 provided methodological contributions via illustrations of how the use of multiple analytical quantitative and qualitative techniques can use used iteratively across multiple data sources to develop rich, descriptive cases of the nature of the collaborative knowledge building discourse that occurred for pairs of sixth grade students within a face-to-face and synchronous mobile digital learning environment. Chapter 3 provided detail on the design and rationale of *WeInvestigate*, that may be used by developers of science curricula and technological learning environments through elucidating how the development and classroom implementation of an innovative, research-based curricular context may be integrated and used in ever-advancing technological contexts to support collaborative science teaching and learning. The findings in Chapter 4 hypothesized the impact of the collabrified technology and additional designed supports for collaboration, which have the potential to contribute in applied and theoretical ways to our understanding of students' paired collaborative discourse via an innovative, research-based curricular context integrated into a mobile app with the capability for synchronous collaboration across multiple features. Lastly, the findings related to the teacher and implementation of *WeInvestigate* presented in this chapter have implications for teachers, teacher educators, and professional developers, by describing the importance of the teacher, challenges the teacher faces, and urging future studies on the role of the teacher in technological environments similar to *WeInvestigate*.

The findings, limitations, and suggestions for future research in the manuscripts presented in this dissertation point to exciting possibilities for future research on students' collaboration using future iterations of *WeInvestigate* with more embedded supports;

comparative studies of students' collaborative use of *WeInvestigate*; and studies focused on elucidating the role of the teacher using *WeInvestigate* for teaching and learning.

The study of sixth grade students' collaborative co-construction of artifacts via synchronous face-to-face and through *WeInvestigate* presented in this dissertation was a unique one in a number of ways. The synchronous nature of *WeInvestigate* across multiple features - video, simulation, model, writing – as well as the face-to-face aspect, distinguishes the technology itself. Further, this dissertation encompassed a study of the entire system of the integrated technology and lessons, which included student interactions with videos, text, modeling, simulations, writing, and other students and the teacher. Additionally, the study was done in a naturalistic setting; that is, a traditional and fairly representative upper elementary science classroom in a challenging school district. This study provided some insight into several types of activities and tasks over time throughout a unit of study, via the combination of quantitative and in-depth qualitative methods. The richness of the cases developed as a result of this study, therefore, provide a contribution to our understanding of students' interactions within a technological and face-to-face learning environment.

The challenges that arose from this study of *WeInvestigate* imply that there is still a ways to go before this kind of instruction – via an entire unit based within a tablet-based app - becomes feasible in K-12 classrooms. Even given the possible affordances of the synergistically-developed curricular unit and technology discussed in this dissertation, we are not yet convinced of the benefits of developing and learning via integrated curriculum-technology units when compared with learning via similarly innovative paper-based curricula and accompanying individual technological tools to supplement classroom instruction. Thus, we encourage continued study of future iterations of *WeInvestigate*, as well as similarly rigorous and reform-

based units embedded within mobile technologies. In-depth studies - such as the one done in this dissertation - of the potential of technological interventions such as *WeInvestigate* are especially important now, given the general public's enthusiasm over recent technological trends such as "blended learning" (e.g., Horn & Staker, 2011), "one to one instruction" (e.g., Penuel, 2006; Chan et al., 2006) and "flipped classes" (e.g., Horn, 2013).

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